The Rural Text-Book Series

EDITED BY L. H. BAILEY

SOILS AND FERTILIZERS

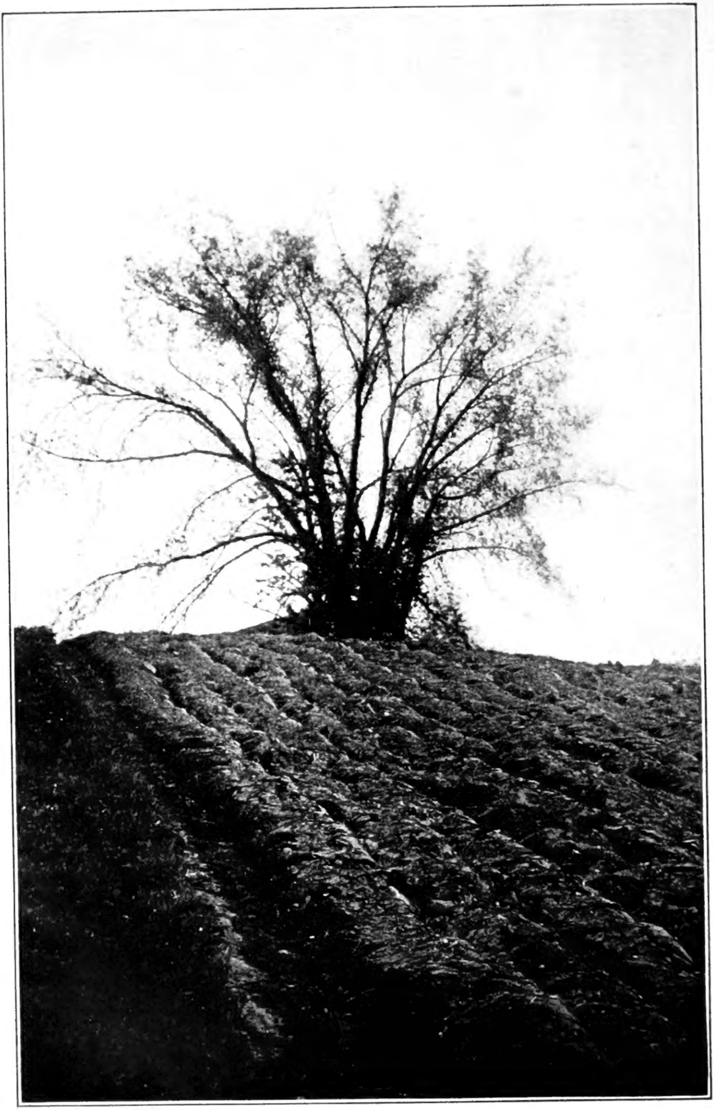

PLATE I. "The earth is perhaps a stern earth, but it is a kindly earth." — BAILEY.

SOILS AND FERTILIZERS

BY

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PREFACE

In many of the high schools and other secondary schools into which instruction in agriculture was introduced a few years ago there has been such a development of the subject that one general text is no longer adequate. In these schools some of the more important phases of the subject now receive a degree of attention that calls for specialized texts. This is particularly true of the secondary agricultural schools and the normal schools. It was with the hope of meeting this need, and also of contributing to the demands of short courses in agriculture and of summer courses for teachers, that this book was written.

The attempt has been made so to present the subject that the pupil who has no knowledge of chemistry or other natural science will be able to understand it. No chemical symbols or formulæ have been used. Use has been freely made of a limited number of names of chemical substances contained in commercial fertilizers which contribute to the nutrition of plants. These, however, are terms with which the pupil can familiarize himself as readily as with the geographical and other names that he has already mastered.

Following each chapter are field and laboratory exercises, designed to illustrate in a concrete manner the teachings of the text. There are more of these than any one teacher will probably find it expedient to have his class perform, but the considerable number and variety of exercises will make it possible for any school to afford the necessary facilities for performing some of the demonstrations.

It has not been thought necessary to cite authorities on which the statements in the text are based. For these and for more complete discussions of most of the matters treated in this book, teachers and others who may wish to pursue the subject further are referred to the college text on soils by Lyon, Fippin and Buckman.

The author is especially indebted to Dr. H. O. Buckman for much assistance and advice. He has contributed practically all of the laboratory exercises.

Ithaca, N. Y.,
June 1, 1917.

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CHAPTER I

SOIL AS A MEDIUM FOR PLANT GROWTH

THE farmer's interest in the soil is due chiefly to what it contributes to plant production. In this respect it performs several functions: (1) it acts as a mechanical support for plants by furnishing a foothold comprising many openings through which plant roots ramify and hold the plant in place; (2) it serves as a receptacle in which water is held in a convenient way for roots to appropriate; (3) it is composed, in part, of substances that dissolve in the water which it holds and are absorbed from solution by roots, and utilized by plants as food material; (4) its porous nature allows air to circulate within it, thus supplying plant roots with air.

These are the contributions that soils make to plant growth. Before proceeding with a more detailed study of soil it will be desirable to consider briefly the needs of the plant as supplied by the soil.

1. **Soil as a mechanical support for plants.** — Land plants need anchorage, for they must have some permanent supply of water and other food material, which is not to be had from the atmosphere. The soil serves, at once, as anchorage and food reservoir. One property of soil that adapts

it especially for the growth of roots is its permeable structure, which furnishes innumerable channels through which roots may ramify; another property is its compressibility, which makes it possible for the roots to grow in thickness by forcing together the surrounding particles. The compacting thus effected may be noted in a field of mangels or other large roots at harvest. The firmness of this anchorage is illustrated by the resistance that large trees offer to heavy winds.

2. Soil as a reservoir for water needed by plants. — The leaves of land plants thrive without being in contact with water, but their roots must have a nearly constant supply. This the soil helps to maintain by catching and holding more or less of the water that falls as rain. The water thus held is in contact with the small roots and root-hairs of plants, and may readily be absorbed by them.

3. Uses of water by plants. — Plants require moisture for several reasons: (1) Water acts as a solvent for substances that are essential to plant growth, and these substances can be absorbed by plants only when they are in solution. (2) Water is itself a plant-food material and it either becomes a part of the cell without change, or is decomposed and its component parts are used in forming new substances. (3) The cells, of which plants are composed, are kept filled and the plant is more or less firm and erect when its cells are extended with water. When not so filled, the plant wilts. (4) Nutritive substances and substances formed from them in the plant tissues are transferred from one part of the plant to another, as occasion requires, by water in the plant. (5) The evaporation of moisture from leaves (transpiration) causes a reduction of temperature in plants, as does evaporation of perspiration from animals.

4. Soil as a source of plant-food materials. — Plants require for their growth certain nutrient substances, of which

some are derived from the air and some from water, but the larger number must be obtained from soil. They may be classified thus:

Substances obtained from air or water:

Carbon	Hydrogen
Oxygen	Nitrogen

Substances obtained from soil:

Nitrogen
Phosphoric acid [phosphorus] [1]
Potash [potassium]
Lime [calcium]
Magnesia [magnesium]
Iron
Sulfur

All these substances are essential to the normal development of farm crops. Carbon, oxygen and nitrogen are found in air. Hydrogen and oxygen are in water. Plants obtain their carbon from the air; their oxygen from both air and water; their hydrogen from water; their nitrogen, in the case of certain plants only, from the air. The other substances are found in all arable soils, from which plants obtain them after they have become dissolved in the soil water. While arable soils contain all these substances, the fact that they must be in solution before plants can use

[1] This list of plant-food materials gives the names commonly used. Thus the terms phosphoric acid, potash, and lime are the ones used in connection with fertilizers. Nitrogen is sometimes spoken of as ammonia by fertilizer manufacturers, but the most general term is nitrogen. The words in brackets following the unbracketed words indicate other names sometimes found, but not used in this book.

All the substances in this list are capable of uniting with certain other substances to form various combinations. When present in the soil they are not likely to be in the same combinations as when present in plants. When, therefore, phosphoric acid in soil or in a plant is spoken of, nothing is implied regarding the form in which it exists.

them sometimes leads to a deficiency in the available supply. This is either because they are not present in sufficient quantity, or because they are not readily dissolved by the liquids with which they come in contact. Many things tend to influence the quantity of these substances that plants may obtain. Among these are tillage, decaying vegetation, drainage and the kind of plant grown. It is the nitrogen, phosphoric acid, potash and possibly sulfur that are most likely to be deficient in the solution to which plants have access, and commercial fertilizers usually contain one or more of these substances.

The kind of fertilizer that it will be desirable to apply depends, in part, on the so-called availability of each of the nutrient substances contained in the soil, availability in this case meaning the readiness with which the plant can appropriate these food materials. But some plants require more of certain of these substances than they do of others. Hence the needs of the plant must also be taken into consideration in deciding what fertilizer to use on a given soil.

5. Quantities of plant-food materials in the earth's crust. — As all of the food materials that plants draw from soil, with the exception of nitrogen, came originally from rocks, it is of some interest to know what the proportions of these substances are in the entire crust of the earth. As stated by Clarke they are present in the following percentages:

Oxygen	47.17	Potash	3.00
Iron	4.44	Sulfur	0.11
Lime	4.79	Phosphoric acid	0.25
Magnesia	3.76		

Nitrogen does not appear in this list because it does not occur as a constituent of the rocks forming the earth's crust. The nitrogen that soil contains is derived from the atmosphere by processes that will be described later. Most of the constituents of soil have, however, been formed from

rock, and hence soil may be expected to have a somewhat similar composition to that of the earth's crust.

It will be seen that two of the important nutrients, as far as plants are concerned, namely phosphoric acid and sulfur, are present in relatively small quantities. Potash, magnesia, lime and iron are present in much larger proportions. This is somewhat the relation in which we are likely to find them in soils, and emphasizes the probable need of phosphoric acid and sometimes sulfur for the maximum production of crops. Potash, in spite of its greater quantity, is often not available in sufficient amount and must be applied as a soluble fertilizer.

Lime, being easily soluble in soil water, has frequently been leached out of soils in such quantities that it must be replaced. Magnesia is less soluble and hence is rarely lacking.

6. Soil-forming rocks. — As the earth, which was once a molten mass, cooled, the crust became solid and this solidified material formed igneous rocks, so called to distinguish them from rocks that were formed in other ways. Some examples of igneous rocks are granite, syenite and basalt. Other kinds of rocks, called sedimentary, have been formed from material derived from igneous rock by solution and sedimentation, and later solidified into rock, often under pressure. Limestone, dolomite, shale and sandstone represent some rocks of sedimentary origin. The first two are quite readily soluble in soil water, having been deposited from solution in the process of their formation. Shale is a more or less hardened clay. Sandstone, as its name implies, consists of sand grains cemented together.

Metamorphic rocks have been formed by heat, pressure, solution and other processes acting on either igneous or sedimentary rocks. These forces have frequently produced rocks quite unlike those originally involved in the process.

Gneiss, marble and slate are among the rocks so formed. Gneiss somewhat resembles granite, from which it is formed, but unlike granite has a layered structure, the result of the pressure to which it was subjected. Marble has been formed from limestone or dolomite by heat and pressure, which have caused crystallization. It is not, therefore, so readily soluble as limestone. Slate has been formed from shale by heat and pressure.

7. **Rock-forming minerals.** — Most rocks are not homogeneous, but are made up of a number of different materials. An examination will frequently show grains of different sizes, colors and hardness. The grains are minerals and they differ from each other in their composition as they do in their appearance. But each mineral always has a more or less well-defined composition, so that when we have a certain mineral we know something of the quantity of potash or lime or other base that it contains. The quantity of potash or other plant-food material in a rock will depend on the proportion of minerals containing those substances that compose the rock.

8. **Important minerals.** — There are a few minerals that it will be well to mention: (1) because they or their products occur in very large quantity in soil and influence its physical properties; (2) because of the plant-food material that they contain. Quartz and feldspar are examples of the class first mentioned. Quartz is found in almost all soils, and may form from 85 to 99 per cent of their composition. It is particularly prevalent in sandy soils. It usually occurs as a large grain, called sand, is hard and insoluble and contributes no plant-food material. A soil with a great deal of quartz is usually a light, easily worked soil.

On weathering feldspar contributes to soils a mass of very finely divided matter known as clay, the smallest of the soil particles. It, therefore, forms part of the clay in

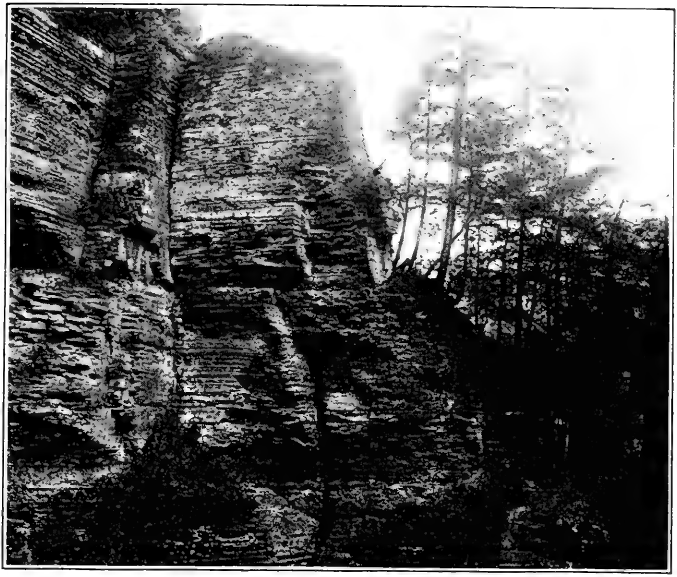


PLATE II. SOIL FORMATION. — Heat, cold, and frost have been largely instrumental in fracturing the rocks in the upper figure, and in producing the rock débris and soil in the lower. Note that vegetation has already well started on the slope.

soils and adds to their plasticity, and in addition, this very fine material is an absorbent, holding the soluble plant-food materials of fertilizers in a form that prevents them from leaching from the soil, and yet gives them up to plants rather easily.

As examples of the second class we again have the feldspars as they furnish lime, magnesia and potash; calcite, which contains lime; hematite, which consists largely of iron; dolomite, which contains both lime and magnesia; apatite, which furnishes phosphoric acid and lime, and gypsum, which is a combination of lime and sulfur.

These minerals and the plant-food materials contained in them may be reviewed in tabular form thus:

Mineral	*Plant-food Material*
Feldspars	Potash, lime, magnesia
Calcite	Lime
Dolomite	Lime, magnesia
Hematite	Iron
Apatite	Phosphoric acid, lime
Gypsum	Sulfur, lime
Quartz	Silica (not a plant-food material)

As these minerals are widely distributed in rocks from which soils are formed, they are found in almost all soils, and thus it is that all the substances required by plants are to be found in most soils.

QUESTIONS

1. What are the properties of soil that make it well adapted to furnish a mechanical support for plants?
2. What relation does soil have to the needs of plants for water?
3. Describe the reasons why plants need water.
4. Name the elemental substances that plants derive from soil.
5. What elemental substance do plants obtain from soil that is not present in rocks from which soil is formed?
6. What two substances necessary to plant growth are contained in the earth's crust in the smallest quantities?

7. In what way were igneous rocks formed? Sedimentary rocks? Metamorphic rocks? Name examples of each.

8. Name a mineral containing potash, a mineral containing lime, a mineral containing magnesia, a mineral containing phosphoric acid, a mineral containing sulfur, a mineral containing iron.

LABORATORY EXERCISES

The following exercises are designed to suggest possible experiments and demonstrations that may be carried out in connection with the various chapters. Some may be performed by the student if adequate facilities are at hand, some are only possible as demonstrations, while others are field studies and depend on local conditions. Enough suggestions are made with each chapter to give the teacher a range of choice according to his conditions and facilities. It is not considered possible or advisable that all the experiments and demonstrations listed be carried out.

Exercise I. — Study of soil-forming minerals. (The teacher will find an elementary text in mineralogy of great aid in this experiment.)

Materials. — Small specimens of quartz, potash-feldspar, mica, calcite, apatite, gypsum and hematite. Also a piece of a glass, a knife, dilute muriatic acid, a hand-lens and flame (gas or alcohol).

Procedure. — Study the specimens according to the following outline, with a view to identifying the minerals unlabeled. Use hand lens where possible

Hardness. — Determine hardness by the following scale.

Hardness	*Mineral*	
Scratched by finger nail	Gypsum	Mica
Cut by knife	Calcite	
Scratched with difficulty with knife	Apatite	
Scratches glass	Feldspar	— Hematite
Scratches glass very easily	Quartz	

Color. — Observe color and luster of the various specimens and determine if it is characteristic and useful in identifying the mineral.

Cleavage and *fracture.* — Do specimens split easily in certain directions or do they fracture? What effect do these characters have upon the appearance of the mineral?

Form. — Do the specimens seem to have any crystal form that is characteristic and useful in identification?

Action of acid. — What is the result if the specimen is treated with a few drops of acid? Explain.

Flame. — Hold a small fragment of each mineral in the flame. Observe fusibility and change of color. Is the flame given any color which is characteristic?

EXERCISE II. — Study of soil-forming rocks.

Materials. — Small specimens of granite, basalt, shale, slate, limestone, sandstone and quartzite.

Procedure. — Study the color, texture, and structure of each sample. Identify the minerals present and from this determine the plant-food materials carried by each rock. Be prepared to identify unlabeled samples in laboratory and field.

EXERCISE III. — To show that plants give off water.

Materials. — Plant growing in small pot, a tumbler.

Procedure. — Place a tumbler over a small plant and observe the condensation of moisture on the sides. Where does this moisture come from? What was its original source? How do plants give off water? Explain uses of water to the plant.

EXERCISE IV. — Conditions for plant growth.

Materials. — Small flower pots, rich soil, oat seed.

Procedure. — Fill four small flower pots with a rich garden loam. Moisten well and plant with oat seeds. When seedlings are a week old, thin to desired number of plants. Grow for a few weeks under optimum conditions and then subject them to the following conditions:

Pot 1. — Sunshine and optimum water.

Pot 2. — Sunshine and minimum water.

Pot 3. — Cold, shade, and optimum water.

Pot 4. — Dark and optimum water.

Observe results and explain. More pots with other conditions may be tried at the pleasure of the teacher.

EXERCISE V. — Effect of the different plant nutrients.

Materials. — One-gallon flower pots, very poor sandy soil, nitrate of soda, acid phosphate, muriate of potash, barley seed.

Procedure. — Fill five flower pots to within an inch of their tops with poor sandy soil. It is essential to the success of the experiment that the soil be poor, and also that it shall be surface soil and con-

tain some plant food material. Weigh the soil that is placed in each pot, mixing with it fertilizer in the following proportions:

Pot 1, nitrate of soda one part to five thousand parts of soil. Pot 2, acid phosphate, one part to five thousand parts of soil. Pot 3, muriate of potash, one part to ten thousand parts of soil. Pot 4, all three of these carriers, each at the rate specified above. Pot 5, no fertilizer. Mix the fertilizer and soil thoroughly before placing in the pots. Plant a dozen or more barley seeds in each pot. Add water in sufficient quantity to make the soil moist but not too wet. Place the pots in a place that is moderately warm during the day, where they will not freeze at night, and where there is abundant light. When seedlings are a week old, thin to ten. Allow plants to grow for use in laboratory exercises in Chapters XI, XII and XIII. Observe growth in each pot.

CHAPTER II

SOIL FORMATION AND TRANSPORTATION

SIDE by side are to be seen rock and soil. On the rock no vegetation is growing except a few lichens and other minute plants. On the soil there is a luxuriant growth of multitudinous plants. Soil is derived from rock. Evidently there must have been a profound change to cause such a difference in their relations to plant growth. In some regions of the earth there is much rock and little soil, while often on the prairie one sees no large rocks, and may plow all day and perhaps not strike even a small boulder. It may be surmised that in connection with the process of soil formation there has been a large transportation of material from one place to another. All this was brought about by natural agencies, most of which are still operating to form more soil and to increase the productiveness of soil already under cultivation.

The process of soil formation is, however, extremely slow, and it must be remembered that thousands and tens of thousands of years have elapsed while the operation has been in progress.

9. Agencies concerned in soil formation and transportation. — The agencies that have brought about these transformations may be listed as follows:

Heat and cold	Ice
Frost	Wind
Water	Gases

Plants and animals

10. Action of heat and cold. — Rocks, as we have seen, are mixtures of different minerals. These minerals have different rates of expansion when heated. Exposed rock will suffer great changes in temperature in twenty-four hours, especially if it be located in a region of high altitude and cloudless weather. A block of marble one hundred feet long will expand one-half inch with a change of 75° Fahrenheit, and this is frequently of diurnal occurrence in an arid climate. Because the minerals composing rock expand and contract at different rates, they tend to tear apart, thus producing crevices that may fill with water, and this water acts still further to disintegrate the rock.

11. Action of frost. — One reason that building stones are more likely to disintegrate in a cold moist climate than in a dry or warm one is that the small pores and cracks on their surfaces fill with water, which, when it freezes, exerts an enormous pressure. The expansive power of freezing water amounts to about 150 tons to a square foot, which is equivalent to a column of rock a third of a mile in height. The rock surface becomes chipped off by repeated freezing and even great masses of rock are detached by the freezing of water in larger cracks, as may be seen beneath rock ledges in the spring of the year.

An interesting example of the effect on rock disintegration of a cold moist climate as compared with a dry one is found in the difficulty that has been experienced in preserving the obelisk, now in Central Park, New York, which had previously stood for many hundreds of years in the Egyptian desert without great damage. It has been found necessary to cover the entire surface of the stone with paraffine in order to preserve the hieroglyphics carved on its surface.

12. Action of water. — Water has another effect on rock. It is a solvent, weak but universal. It acts on all minerals, dissolving slight quantities of some, considerably more of others.

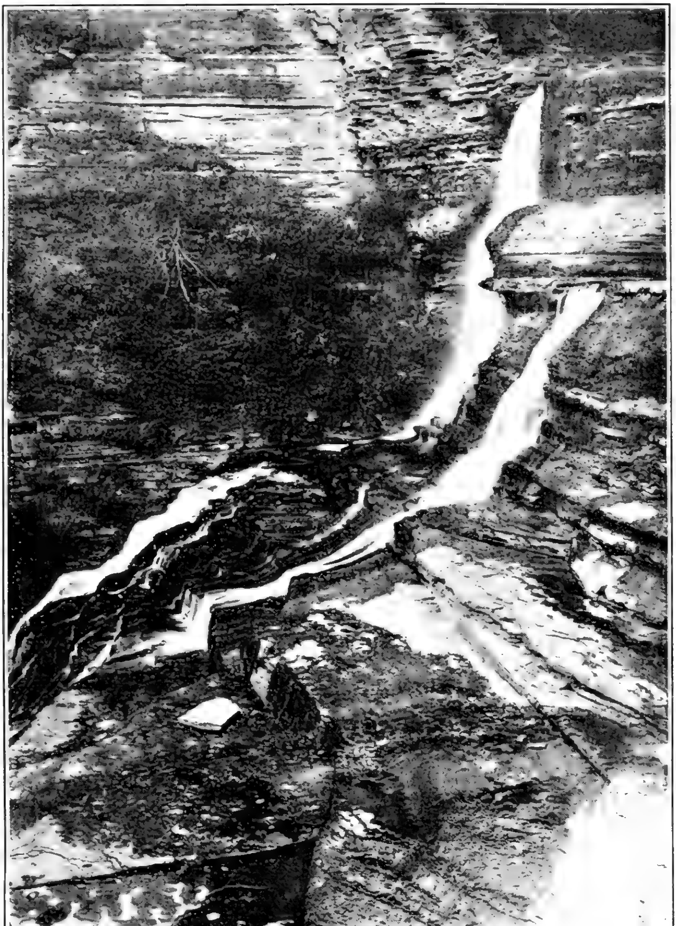


PLATE III. WATER EROSION. — The wearing action of water is slow but constant, and is leveling the surface of the earth at the rate of an inch in several hundred years.

It is as a transporting agent that water is most active. From the time when raindrops beat down on the surface of the soil, while they are gathering into rivulets and the rivulets are becoming rivers that discharge into the ocean, they are engaged in moving particles of rock débris and soil. It is estimated that the United States is being planed down at the rate of one inch in seven hundred and sixty years. This is rapid enough if it were applied at one point to dig the Panama Canal in seventy-three days.

The carrying power of water has resulted in the formation of the rich river valley soils that have been deposited by the streams flowing through them. The coastal soils and lake soils have also been transported by water.

13. Action of ice. — In former times a considerable part of the northern United States was covered by huge masses of ice, known as glaciers. These ice masses were of enormous volume and moved slowly in a southerly direction. The great thickness of the ice mantles, amounting to several thousand feet at some places, caused them to cover hills, valleys and mountains, and their enormous weight ground rock surfaces, pushed forward heaps of soil and transported huge boulders. The southern limit of the glaciers corresponded roughly to the lines now marked by the Ohio and Missouri rivers, and again extended farther southward along the Pacific coast. It met the Atlantic coast at about the present location of New York. Changes of climate caused an alternate recession and extension of the ice sheets several times, and during all this period soil was being formed and worked over by the ice and the water that melted from it. When the glacier melted, stranded ice masses remained behind. These formed lakes in which soil was reworked and shifted, and as the lakes finally drained off, the reworked soil was left behind. These glacial soils are, as a rule, productive, because of the thorough pulverization and mixing they have received.

14. The action of wind. — That wind has been an active factor in the transporation of soil is evident to any one who has lived in an arid or semi-arid region, where dust storms are not infrequent. In a humid region the movement of soil by wind is not so patent, but even there, especially along the seacoast, there is some movement of this kind. There is also an erosive action produced by wind, but this has not been very important. However, in arid regions the sand-bearing wind has been instrumental in wearing away large surfaces of rock, the eroded portions of which have helped to form soil.

The most important result of wind action has been the production of loessial soils, which are found in parts of Wisconsin, Illinois, Iowa, Missouri, Nebraska and Kansas, also in the valley of the Rhine and in parts of China. Another result is the production of adobe soils, which are found in mountain sections of western and southwestern United States. While these soils do not owe their present location entirely to the action of wind, that element has played a large part in removing them from other regions and depositing them where they now are.

15. Action of gases. — Of the gases that compose the normal atmosphere, oxygen and carbon dioxide are instrumental in decomposing rock and soil. They unite chemically with some of the substances composing rocks, and when the new compound thus formed is more soluble than the original substance, the resistance of the rock to water is decreased. This is a very constant operation, and as air penetrates deeply into soil and into the pores of rock its action is widespread.

16. Action of plants and animals. — Some of the lower forms of plants, of which lichens are a notable example, are able to live on the bare surfaces of rock, fastening themselves to the small crevices and pores and in the process of

their growth causing the rock to decay and organic matter to accumulate in the crevices. These plants are followed by higher vegetation, the roots of which are larger; when these roots extend themselves into cracks in the rock they exert a prying action when wind gives the plant a swaying motion.

After rock becomes sufficiently pulverized to produce soil, plants are active agents in decomposing soil particles by the solvent action of the acid secreted by their roots and formed by their decay.

Very small plants, included among the microörganisms because they are too small to be seen without a microscope, are also concerned in rock decay. Their action is exerted principally in soil, and is due to the production of acids even stronger than that secreted by the roots of higher plants.

17. Powdered rock is not soil. — We have seen that in the process of soil formation the rock is pulverized, but the process of weathering to which nature resorts is different in its result from merely grinding rock in a crusher or mortar. At the same time that the particles are becoming smaller, certain chemical changes are going on that produce a material having a different composition from the original rock. One result of the transition is the removal of a part or sometimes all of the more soluble constituents of the rock. The percentage loss of some of the constituents of granite and of limestone in the process of forming a clay is as follows:

Table 1. — Percentage Loss of Plant-Food Materials in Granite and Limestone in Process of Soil Formation

Constituents	Percentage of Loss	
	Granite	Limestone
Phosphoric acid	0.00	68.78
Potash	83.52	57.49
Lime	100.00	99.83
Magnesia	74.70	99.38

This table represents merely two cases, and is not meant to imply that these losses always occur in just these proportions whenever rocks of this type are converted into soil. It will be noticed that some of the most valuable plant-food materials are lost in large quantities. For instance, practically all the lime has been lost, as has also a large proportion of the magnesia and potash. Phosphoric acid shows great variation in respect to loss.

Other changes that occur in weathering include the formation of extremely fine particles that give plasticity to soils, and that have the property of absorbing certain substances, like fertilizers, from solution and holding them in a condition in which they do not leach readily from the soil, and yet in a form in which roots may make use of them. As these particles are very small, we find a relatively large proportion of them in a clay soil, but a very small proportion in a sand.

Another operation that accompanies soil formation is the incorporation of vegetable matter or animal remains — together called organic matter — with the soil particles. This adds greatly to the crop-producing power of a soil, for as the organic matter decays it makes more soluble the inorganic constituents.

QUESTIONS

1. Name the agencies concerned in soil formation and transportation.
2. In what way do heat and cold act to decompose rock?
3. What is the action of frost on rock?
4. How does water aid in the transportation of soil?
5. What part did the great glaciers play in soil formation?
6. Has wind been more potent as a soil former or as a transporter?
7. Describe the ways in which roots aid in the decomposition of rocks.
8. Explain the difference between powdered rock and soil.

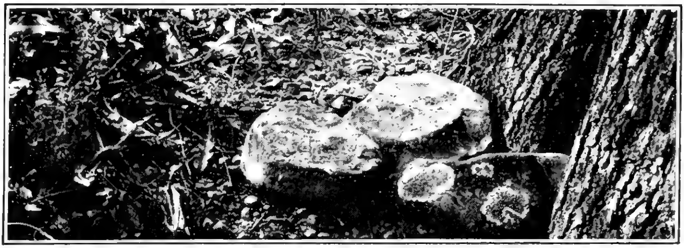


PLATE IV. PLANTS AS SOIL FORMERS. — Plants are active agents in the decomposition of rock. In the upper figure lichens may be seen beginning the disintegration, and in the lower, large tree roots are forcing themselves into the cracks in the rock.

LABORATORY EXERCISES

Exercise I. — Soil formation and transportation.

This exercise is based on observations in the field and its value depends on examples available. Use Chapter II as a basis for the field observations.

If rock outcrops can be found in the neighborhood, a visit to them would be worth while. Examples of wind action, heat and cold, frost, and plant and animal influences in forming or transporting soil should easily be found. The erosive and carrying power of streams should also be studied in relation to soil formation.

An examination of weathered rock of various kinds should be made in order to illustrate the chemical phase of soil formation. The rusting of iron could be used as an example of the effect of gases. The iron of rocks rusts in the same way. This, together with the assumption of water and a loss of soluble materials, brings about the decay of the rock. Remember, however, that the physical and chemical agencies work hand in hand and that these agencies are as active upon the soil as upon the original rocks. An examination in the spring of fall-plowed land would permit a study of the effect of weathering on soil structure.

CHAPTER III

SOIL FORMATIONS

From the preceding description of the processes of soil formation, it will be seen that the operation may involve the transfer of soil from one place to another, or that it may take place in one locality, leaving the resulting soil where the parent rocks stood. The latter soils are called sedentary, the former transported. These may again be subdivided as follows:

Sedentary	Residual — formed in place
	Cumulose — plant remains
Transported	Colluvial — gravity deposits
	Alluvial — stream deposits
	Marine — ocean deposits
	Lacustrine — lake deposits
	Glacial — ice deposits
	Æolian — wind deposits

18. Residual soils. — Soils of this formation are geologically old, that is, they were formed at an earlier period than any of the other arable soils. They always bear more or less resemblance in composition to the rocks underlying them, although on account of their great age they have lost much of the more readily soluble constituents of the original rock. This is also of agricultural significance, because many of these soluble constituents are of great importance

in the growth of plants. The following table shows the partial composition of an Arkansas limestone and of the clay soil formed from it, also the percentage of each of the constituents lost in the process:

Table 2.— Partial Composition of Limestone Rock and Its Residual Clay

Constituents	Percentage Composition		
	Rock	Soil	Lost
Potash	0.35	0.96	66.36
Lime	44.79	3.91	98.93
Magnesia	0.30	0.26	89.38
Iron	2.35	1.99	89.56
Silica	4.13	33.69	0.00

It will be seen from the above table that lime, magnesia and potash have disappeared in large quantities, as has also iron, but that silica has lost little or none of what was originally present, and now constitutes by far the larger part of the soil. Silica although not of great importance as a plant nutrient is, nevertheless, of value in crop production, because it contributes to the formation of the absorptive compounds before mentioned.

The great age of residual soils has also led to changes in the composition of iron compounds, producing usually those of a red or yellow color, these colors being characteristic of residual soils. The long period of weathering has frequently resulted in wearing down the particles to such a degree of fineness that heavy soils of the nature of clay, clay loam or silt are produced.

Analyses of two typical residual soils from Virginia, that have been formed from gneiss and limestone respectively, are given in the following table:

TABLE 3. — PERCENTAGE COMPOSITION OF TYPICAL RESIDUAL SOILS FROM VIRGINIA

CONSTITUENTS	ORIGINAL ROCK	
	Gneiss	Limestone
Phosphoric acid	0.47	0.10
Potash	1.10	4.91
Lime	trace	0.51
Magnesia	0.40	1.20
Iron	12.18	7.93
Silica	45.31	57.57

A striking feature is their low lime content, which is characteristic of soils that have been long subjected to leaching. Such soils would require applications of lime for the profitable production of most crops. The low content of lime in the soil derived from limestone illustrates the fact that such an origin does not insure a satisfactory supply of lime.

19. Distribution of residual soils. — These soils are widely distributed in the United States, being found in four great provinces — the Piedmont plateau along the eastern slope of the Appalachian mountains, the Appalachian mountains and plateaus, the limestone valleys and uplands between and west of these mountains, and the Great Plains west of the Mississippi and Missouri rivers.

20. Cumulose soils. — Unlike residual soils, cumulose soils are of very recent origin. They have been formed by the growth of vegetation in and around lakes, ponds and marshes, many of which were left by the retreating glaciers. As the plants die they become immersed in water, which shuts off the supply of air, and thereby arrests decomposition. The partly decomposed plant remains accumulate

until the surface of the water is reached, when larger plants take root, and it is not uncommon to find large forests covering soil formed in this way. Cumulose soils, as may be expected from their mode of formation, contain a very large proportion of organic matter. On the basis of the degree of decomposition of the organic matter they have been divided into two classes — peat and muck. In peat the stem and leaf structure of the original plants may still be detected. In muck, however, decomposition has gone so far that the organic matter forms a more or less homogeneous mass, and is mixed with a larger proportion of mineral matter than in peat.

Peat is used extensively as fuel in some European countries, but is not of much value for agricultural purposes. The degree of decomposition reached by the organic matter determines its usefulness for both these purposes. Muck cannot profitably be used for fuel, but some muck lands are highly prized for market-gardening and other of the more intensive agricultural operations.

The following table shows the composition of some typical cumulose soils:

TABLE 4. — PERCENTAGE COMPOSITION OF SOME CUMULOSE SOILS

CONSTITUENTS	PERCENTAGE COMPOSITION		
	Muck	Muck	Marsh Mud
Mineral matter	31.60	24.79	80.40
Organic matter	68.40	67.63	15.77
Nitrogen	2.63	2.03	[1]
Phosphoric acid	0.20	0.19	0.15
Potash	0.17	0.15	0.65

[1] Not determined.

Many muck soils are underlaid by deposits containing lime derived from shells of aquatic organisms that inhabited the bodies of water in which the muck was formed. This adds materially to the value of the land, as lime is a valuable soil amendment, particularly on muck land. It is well to keep this in mind when examining muck land.

The percentage of potash is much lower than in any other kind of soils, and a potash fertilizer is usually of great benefit to crops planted on muck.

21. Colluvial soils. — On all steep slopes there is a gradual downward creep of soil particles due to the effect of gravity assisted by rainfall, freezing and thawing, the movements of animals, in fact any agency that starts the particles in motion, after which their direction is almost invariably downward. This soil formation is not extensive, nor in any sense important. Such soils are confined largely to the bases of mountains. They are usually shallow and stony.

22. Alluvial soils. — A stream flowing through its valley will erode its bed if very steep and will deposit sediment if nearly level, but under most circumstances it both erodes and deposits soil. As the upper reaches of a river are usually of steeper grade than the lower, it often happens that considerable material is picked up by the stream near its source, and as the current becomes slower farther down, this material is deposited. Alluvial soil is, therefore, found most largely along rather slowly flowing streams.

It is estimated that water flowing at the rate of three inches a second will carry only fine clay, but if this rate is increased to twenty-four inches a second, pebbles the size of an egg will be moved along the stream bed.

It is quite customary for streams flowing through a flat region both to erode and deposit soil. Such streams are likely to be sinuous in their course, the curves gradually becoming more angular as the current erodes the soil from

the concave bank and deposits it on the convex. Finally the curve becomes so great that the stream breaks through the banks and straightens its course. In this way a broad valley may gradually be covered by sediment deposited by the stream.

Changes in velocity of a stream, as when in flood after heavy rains or melting snows, cause a change in its carrying power. Much material will be picked up by a stream in flood that must be deposited as the flood subsides. A stream may build up its bed so that the surface of the water is higher than is the land at some distance on either side. Such is actually the case in the lower Mississippi valley.

23. Character and distribution of alluvial soils. — Alluvial soils may be sands, loams or clay, depending on the velocity of the stream and the nature of the eroded material. It is likely to be the case that the alluvial deposits along the upper stretches of a stream will be sandy, and that the material deposited will become finer as the stream proceeds. Soils of this formation have no very distinctive composition. Naturally this character depends on the nature of the material farther up the stream, and this, of course, varies in different parts of the country. Even along any one stream there may be a wide diversity of material picked up and hence an alluvial soil is likely to be a heterogeneous one. The content of organic matter is usually high, as this is carried and deposited with the other matter. Alluvial soil is generally regarded as rich soil, but there are many exceptions. When situated along slowly flowing streams, the land is likely to need drainage.

Alluvial soils are naturally confined to the margins of streams, but they are found along small as well as large ones, and consequently the aggregate area of alluvial land is large. The Mississippi valley and its branches contain

the largest area of alluvial soil found anywhere in the United States. Rivers flowing through the coastal plain are all well lined with alluvial soil adjacent to their banks.

24. Marine soils. — Soils of this formation have been made by material carried by rivers and deposited in the ocean, whence they afterwards emerged by elevation of the sea bottom. They, therefore, resemble alluvial soil that has been worked and reworked by sea water. They are generally sandy soils, as the solvent action of water and the pulverizing force of waves has disposed of most of the minerals except quartz. They are light not only in texture, but also in color. They are nearly always deficient in organic matter. Their sandy nature fits them particularly well for trucking, and it is to that industry that a large area of marine soil is devoted.

25. Distribution of marine soils. — A fringe of land averaging many miles in width along the Atlantic coast from Long Island southward and including all of Florida is composed of marine soil. This fringe then turns westward and extends along the Gulf coast in a wide band as far west as the Rio Grande. The alluvial plain of the Mississippi river cuts through the belt, but at this point the marine soil extends as far north as Tennessee. In the aggregate the marine soils constitute a large area of important agricultural land producing cotton, corn and other farm crops, as well as truck crops for which they are especially adapted.

The following is a statement of the analysis of a typical marine soil from the coastal plain in Maryland:

TABLE 5. — PERCENTAGE COMPOSITION OF A TYPICAL MARINE SOIL

Phosphoric acid	0.05	Magnesia	0.35
Potash	0.70	Iron	0.91
Lime	0.41	Silica	92.30

PLATE V. SOIL FORMATION. — The upper figure shows a glacial till soil, the lower an alluvial soil.

A striking peculiarity of this soil is the high percentage of silica, due to the fact that quartz is highly resistant to the constant working to which the particles have been subjected and which has removed much of the phosphoric acid, potash, lime and magnesia. Soils of this particular type contain little fertility, but respond well to fertilization.

26. Lacustrine soils. — These soils have been formed in the beds of lakes both ancient and comparatively modern. The older ones were formed in the glacial lakes, and both are soils that have been worked over by water. They constitute good agricultural soils and are found from New England westward along the Great Lakes, and spread out in a wide area in the Red River valley.

27. Glacial soils. — The tremendous grinding to which rocks have been subjected by glacial action has resulted in a large proportion of very fine particles, and consequently these soils and subsoils are likely to be rather heavy. The particles are jagged instead of having the rounded appearance found in older soils and soils that have been worked over by water for longer periods.

Owing to the fact that this process of soil formation has employed mechanical rather than chemical agencies the soils resemble the parent rock very closely. Unlike residual soils, glacial soils when formed from limestone are generally rich in lime. If, on the other hand, glacial soils are formed from rocks poor in lime, they have a small lime content. The hill soils of southern New York (Volusia series) are derived from shales poor in lime and the soils share this quality, while certain glacial soils of the Mississippi valley (Miami series) that are formed from limestone and sandstone are rich in lime.

In the following table are shown analyses of residual and glacial soils from Wisconsin, the original rocks from which they were formed having been largely limestone:

TABLE 6. — PERCENTAGE COMPOSITION OF RESIDUAL AND GLACIAL CLAYS FROM WISCONSIN

CONSTITUENTS	RESIDUAL		GLACIAL	
	1	2	3	4
Phosphoric acid	0.02	0.04	0.05	0.13
Potash	1.61	1.61	2.36	2.60
Lime	0.85	1.22	15.65	11.83
Magnesia	0.38	1.92	7.80	7.95
Iron	5.52	11.04	2.83	2.53
Silica	71.13	49.13	40.22	48.81

It will be seen that of the substances important for their plant-food value phosphoric acid and potash are somewhat more abundant in the glacial soils, that lime and magnesia are very much more abundant, while the less consequential substances are present in large quantity in the residual soil. This is because the residual soil has been subjected to more leaching.

28. Æolian soils. — Following the retreat of the glaciers there ensued a period of aridity, especially in the southwest section of the territory now a part of the United States. Into these regions there had been washed a large quantity of fine glacial till, and during the dry period this was blown, by high westerly winds, into a large area in the Mississippi and Missouri valleys, where it is now found. It has been given the name of loess and on account of its wide area and great fertility it is an important agricultural soil.

These soils are frequently of great depth, their texture is favorable to the maintenance of good tilth and in prairie regions their long period in grass, before they were placed under cultivation, has given them a good supply of organic matter. The following table contains a statement of analysis of soils from different sections of the loessal area:

TABLE 7. — PERCENTAGE COMPOSITION OF LOESS

CONSTITUENTS	LOCATION OF SOIL			
	Iowa	Mississippi	Missouri	Wyoming
Phosphoric acid	0.23	0.13	0.09	0.11
Potash	2.13	1.08	1.83	2.68
Lime	1.59	8.96	1.69	5.88
Magnesia	1.11	4.56	1.12	1.24
Iron	3.53	2.61	3.25	2.52
Silica	72.68	60.69	74.46	67.10

All of the important plant-food materials, particularly lime, are abundant in these soils. They rarely need liming, and up to the present time commercial fertilizers have been used but little on them.

Adobe is the name applied to another æolian soil similar to loess in its physical qualities, but differing somewhat in its mode of formation. It is supposed to be a mixture of loess with débris from the mountain slopes and has been formed under arid conditions. The soils thus formed are extremely fertile when placed under irrigation, which is usually necessary for their cultivation, because they are found in Colorado, Utah, southern California, Arizona, New Mexico and arid portions of Texas. The composition of two typical soils is given below:

TABLE 8. — PERCENTAGE COMPOSITION OF TWO ADOBE SOILS

CONSTITUENTS	A	B
Phosphoric acid	0.29	0.94
Potash	1.21	1.71
Lime	2.49	13.91
Magnesia	1.28	2.96
Iron	4.38	5.12
Silica	66.69	44.64

These soils show a remarkably high content of phosphoric acid and an abundant supply of the other substances needed by plants.

Sand dunes and volcanic dust are two other forms of æolian soils but nowhere are these soils of much agricultural importance.

QUESTIONS

1. How may soils be divided with respect to the localities in which they have been formed ?

2. What common plant-food materials have been lost in greatest quantities by residual soils ? Why are these soils likely to have a large proportion of clay ?

3. In what four regions of the United States are residual soils found to be predominant ?

4. What is the characteristic constituent of cumulose soils ? For what agricultural purposes are muck soils largely used ? In what important plant nutrient are they likely to be deficient ?

5. How is the velocity of a stream likely to affect the nature of a soil with respect to its proportion of sand and clay ? What kinds of streams form little alluvial soil ?

6. Why are marine soils characteristically sandy ? For what agricultural industry are they frequently used ?

7. Are marine soils usually rich or poor in plant-food materials ? Why ?

8. State over what areas in the United States lacustrine soils are found.

9. Why do glacial soils resemble chemically the rocks from which they were formed ? What is a characteristic difference between residual soil and glacial soil when both are formed from rocks rich in plant-food materials ?

10. Describe the mode of formation of the two principal kinds of æolian soils in the United States. Are they characteristically rich or poor in plant-food materials, and in what one particularly ?

11. Using any map of the United States as a base (preferably a colorless map showing the state boundaries and river courses), draw lines tracing roughly the regions occupied by residual, alluvial, marine, glacial, and æolian soils. These areas may then be shaded or colored differently and a soil map of the United States thus be made.

PLATE VI. STRATIFICATION. — The upper figure illustrates stratification of rock, the lower stratification of soil. This shale rock has at one time been soil. The soil may sometime be rock.

LABORATORY EXERCISES

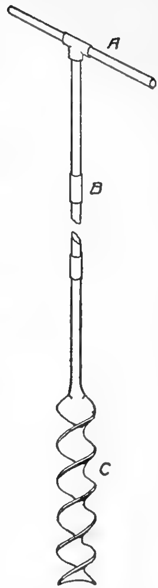


FIG. 1. — Auger for taking soil samples. (*A*) handle, (*B*) joint, (*C*) worm with modified cutting edge.

EXERCISE I. — Classification of soils.

A study of the various kinds of soils must necessarily be made in the field. No one locality affords examples of all the different kinds of soil listed in Chapter III. In some places only one or two classes may be available. In any case make all possible use of the materials, studying each soil as to origin, parent rock, color, depth, subsoil, organic matter, drainage, general fertility and crop adaptability.

EXERCISE II. — Use of the soil auger in taking soil samples.

Material. — Soil auger and jars or bags for samples.

Procedure. — Explain the construction of a soil auger and then proceed with the taking of a sample of the first eight inches of soil, removing the soil in two portions. Then clean out a hole larger than the auger worm to prevent contamination of later samples and take the second eight inches in the way already described. Place samples in bags or jars for future reference or exhibition. Be sure that the samples are representative of the soils to be studied.

These samples may be used later in the tests for organic matter, acidity, water retention, and other demonstrations according to directions in the laboratory exercises to be found elsewhere in the book.

CHAPTER IV

TEXTURE AND STRUCTURE OF SOILS

As a result of the grinding to which rock is subjected in the process of soil formation, there are to be found in soils particles of all sizes, from gravel and coarse sand down to particles so minute that they cannot be seen with the highest power microscope, to say nothing of the unassisted eye. In all but very sandy soils, particles are generally gathered into clusters or granules. Texture is a term used in reference to the size of the particles in a soil; the term structure refers to the arrangement of particles into granules.

29. Shape of particles. — There is no universal shape for soil particles. They vary from spherical to angular, and are sometimes rather elongated, but the occurrence of anything like needle shape is not common. Soils formed by erosion and wave action are likely to have rounded particles, as are also soils formed from limestone.

30. Space occupied by particles. — The number of particles in a given volume of soil can only be estimated, their minute size precludes an actual enumeration. It has been estimated that the number of particles in a gram of soil of certain different kinds is as follows:

Early truck	1,955,000,000
Truck and small fruit	3,955,000,000
Tobacco	6,786,000,000
Wheat	10,228,000,000
Grass and wheat	14,735,000,000
Limestone	19,638,000,000

If all the particles were spheres, it is estimated that each cubic foot of soil would have a surface area on its particles amounting to from two to three and one-half acres.

31. Mechanical analysis of soils. — A separation of the particles of a soil into groups, each of which comprises particles whose sizes fall within certain definite limits, is

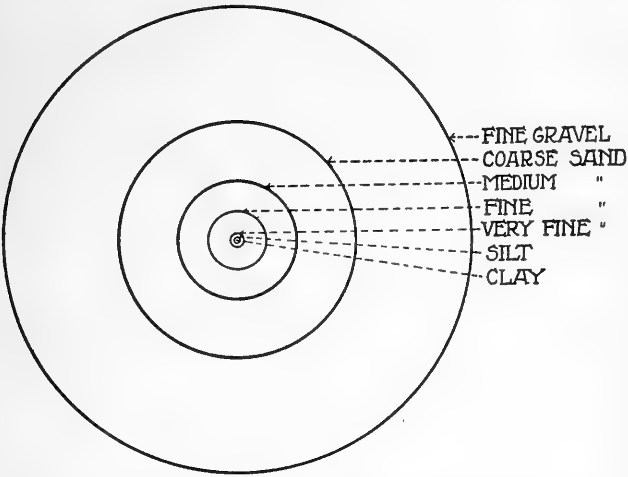


Fig. 2. — Relative sizes of soil particles in the various grades into which a mechanical analysis separates a soil. All are enlarged many times. Particles of fine gravel may vary in size from the largest circle to the next largest; coarse sand from the second to the third; medium sand from the third to the fourth, and so on. The dot in the center represents the largest clay particles; the smallest cannot be shown in a figure of this magnification.

called a mechanical analysis of the soil. The size limit of these groups is a purely arbitrary matter, consequently it is desirable that a universal system shall be adopted. The classification in general use in this country is one proposed by members of the Bureau of Soils of the United States Department of Agriculture. It provides for groups of the following sizes:

Separates	Diameters of Particles	
	Millimeters	Inches
Fine gravel	2–1	0.08–0.04
Coarse sand	1–0.5	0.04–0.02
Medium sand	0.5–0.25	0.02–0.01
Fine sand	0.25–0.10	0.01–0.004
Very fine sand	0.10–0.05	0.004–0.002
Silt	0.05–0.005	0.002–0.0002
Clay	less than 0.005	less than 0.0002

32. Mechanical analysis of some typical soils. — When soils are analyzed according to the mechanical separation just described, there are shown to be great differences between some of them, and soils that are adapted to certain crops are found to have a somewhat characteristic composition. It must be remembered, however, that such distinctions are always limited by climate. The following table, based on the work of the Bureau of Soils and the Minnesota Experiment Station, contains a statement of the mechanical analyses of a number of typical soils:

TABLE 9. — MECHANICAL ANALYSES OF SOILS AND SUBSOILS ADAPTED TO CERTAIN CROPS

<table>
<tr><th></th><th>Coarse Sand</th><th>Medium Sand</th><th>Fine Sand</th><th>Very Fine Sand</th><th>Silt</th><th>Clay</th></tr>
<tr><td>Garden truck soil, Norfolk, Virginia</td><td>1.42</td><td>28.27</td><td>38.25</td><td>7.51</td><td>21.04</td><td>7.15</td></tr>
<tr><td>Garden truck soil, Jamaica, Long Island</td><td>19.06</td><td>24.91</td><td>9.65</td><td>10.08</td><td>17.39</td><td>7.25</td></tr>
<tr><td>Grass soil, Hagerstown, Md.</td><td>0.08</td><td>0.13</td><td>0.53</td><td>10.94</td><td>23.69</td><td>51.75</td></tr>
<tr><td>Wheat and grass subsoil, Kentucky</td><td>0.00</td><td>0.15</td><td>0.25</td><td>2.34</td><td>39.92</td><td>51.77</td></tr>
<tr><td>Corn subsoil, Nebraska</td><td>0.00</td><td>0.00</td><td>0.10</td><td>25.83</td><td>57.00</td><td>9.49</td></tr>
<tr><td>Potato soil, Minnesota</td><td>0.00</td><td>59.04</td><td colspan="2">5.60</td><td>28.40</td><td>4.05</td></tr>
<tr><td>Wheat soil, Minnesota</td><td>0.00</td><td>0.00</td><td colspan="2">6.18</td><td>30.60</td><td>57.00</td></tr>
</table>

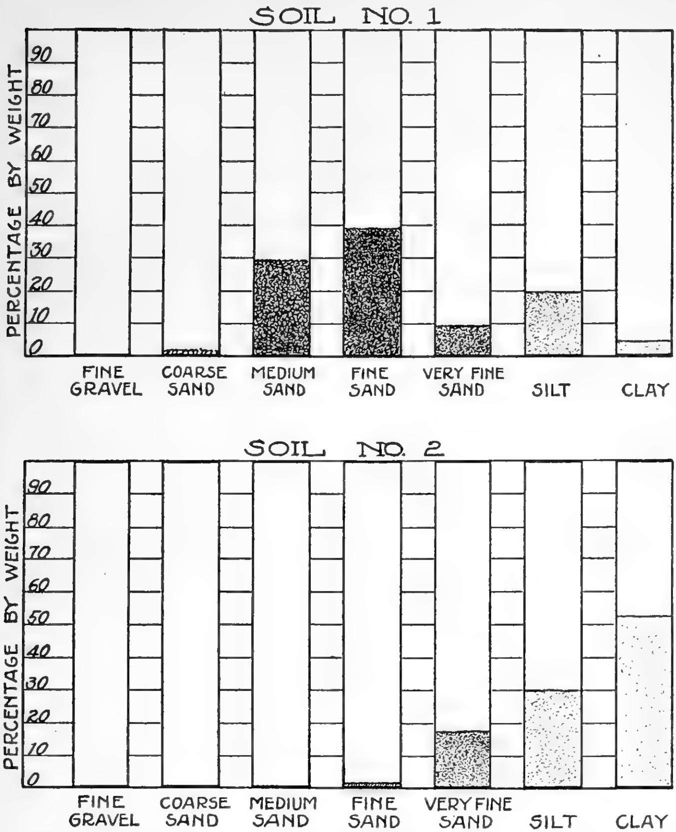


Fig. 3. — Graphic statement of mechanical analyses of two soils. No. 1 is a very sandy soil, and it will be noted that the bulk of its particles consist of medium and fine sand. No. 2 is a heavy clay and its particles belong mainly to the silt and clay divisions.

33. Soil class. — The terms "sandy soil," "loam soil," "clay soil" and the like have been in such general use and are so convenient that attempts have been made to devise a systematic classification on this basis. A soil class is made

up of particles of various sizes, but the proportion of the large, medium or small particles determines the class to which it belongs. The following table published by Whitney will show what percentages of soil separates are contained in an average sample of each of the soil classes.

TABLE 10. — MECHANICAL COMPOSITION OF VARIOUS SOIL CLASSES BASED ON AVERAGES OF MANY ANALYSES

	Fine Gravel	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt	Clay
Coarse sands . . .	12	31	19	20	6	7	5
Sands	2	15	23	37	11	7	5
Fine sands . . .	1	4	10	57	17	7	4
Sandy loams . . .	4	13	12	25	13	21	12
Fine sandy loams .	1	3	4	32	24	24	12
Loam	2	5	5	15	17	40	16
Silt loams	1	2	1	5	11	65	15
Sandy clays . . .	2	8	8	30	12	13	27
Clay loams . . .	1	4	4	14	13	38	26
Silty clay loams . .	0	2	1	4	7	61	25
Clays	1	3	2	8	8	36	42

There must be a certain amount of variation in the percentages of the separates that go to make up a soil class. In order to determine the class to which a soil belongs when its mechanical analysis is known, the diagram in Fig. 4 may be used. If, for instance, a soil contains 40 percent of silt and 15 percent of clay, lines are drawn from the point marked 40 percent silt and 15 percent clay, the lines being parallel to the sides of the right angle formed at *O*. It will be found that these lines intersect in the space marked loam, which is the class to which the soil belongs. If a soil has 20 percent silt and 10 percent clay, the intersection of the lines drawn from these points falls in the space marked sandy loam, and the soil belongs to that class.

34. Some properties of the separates. — In addition to differences in their size, there are other distinctions that are more or less characteristic of these separates. A mechanical analysis, therefore, tells us something about several of the properties of a soil. Clay particles, by reason of their minute size, tend to make a soil plastic and may cause it to become hard, compact and cloddy when dry. Silt does this to a much less degree. The extent to which a soil exhibits these properties depends on its content of clay or silt. Soils containing much clay or silt must not be plowed when wet or they will puddle. Both clay and silt serve to increase the water-holding power of a soil, and clay especially increases the difficulty of tillage.

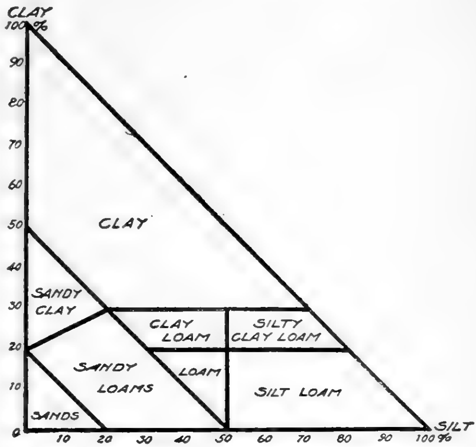


Fig. 4. — Plan by which the soil class may be ascertained from a mechanical analysis.

The sand separates have the opposite properties of clay, and in the order of their greater size of particles. Sandy soils are more easily worked, are not likely to puddle or to form clods, and do not hold a large amount of water, but on the contrary have a tendency to become dry. Sandy soils are termed "light" soils because they are easy to till; clay soils are called "heavy" because they make a heavy draft on the plow.

The absolute specific gravity, or weight of the particles as compared with the weight of the volume of water which

these particles would displace if they were immersed in it, does not necessarily correspond to these terms. Particles of greater and less specific gravity are scattered through both "light" and "heavy" soils and if we are to find the specific gravity of a soil we must have in the sample to be tested enough particles to give an average of all in the soil.

35. Chemical composition of soil separates. — The fact that one kind of mineral wears down to a small particle more easily than does another indicates that there would be a preponderance of resistant minerals, like quartz, among the coarse particles and a large proportion of the more easily decomposed minerals, like the feldspars, among the fine particles. This is actually the case, and it indicates a chemical difference in the separates. Analyses of separates made by the Bureau of Soils of the United States Department of Agriculture bring out these differences, as shown by the following table:

TABLE 11. — CHEMICAL COMPOSITION OF SOME SOIL SEPARATES

Soils	Percentage of Phosphoric Acid			Percentage of Potash			Percentage of Lime		
	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
Crystalline residual .	.07	.22	.70	1.60	2.37	2.86	.50	.82	.94
Limestone residual .	.28	.23	.37	1.46	1.83	2.62	12.26	10.96	9.92
Coastal plain . .	.03	.10	.34	.37	1.33	1.62	.07	.19	.55
Glacial and loessial .	.15	.26	.86	1.72	2.30	3.07	1.28	1.30	2.69
Arid . .	.19	.24	.45	3.05	4.15	5.06	4.09	9.22	8.03

It will be noted from this table that, in general, the smaller particles are richer in phosphoric acid, potash and lime than

are the larger ones, the only exception being the lime in the limestone residual. The arid soils do not show as great differences as do the others, because they have not been subjected to the same amount of solvent action and trituration.

36. Soil structure. — By soil structure is meant the arrangement of the particles of which the soil consists. These particles may be separated so that each is free to move independently of any other, which is usually true of a dry coarse sand. Such an arrangement is known as the separate grain structure. On the other hand the particles may be arranged in small groups or granules, these being so firmly combined that the granule acts like a separate particle. The latter condition is termed the granular or crumbly structure. When applied to loams and clay soils, these arrangements of the particles have a relation to the condition popularly known as tilth. Good tilth in clays and loams implies a granular structure, poor tilth a separate grain structure.

The granular structure is not to be confused with a cloddy condition of the soil. In fact clods have the separate grain structure, because the soil has been worked when wet until the granules are broken down and the particles move easily over each other owing to the lubrication of the moisture.

37. Relation of structure to pore space. — The arrangement of the soil particles determines to a considerable degree the amount of free or pore space within the soil, especially in loams and clays. Merely for the purpose of illustrating this let us suppose that the soil particles are perfect spheres of equal size, which, of course, they are not. There would be two arrangements possible, if each sphere were independent of every other: (1) in columnar order, in which each particle is touched on four places by its neighbors; (2) oblique order, in which each particle is in contact with six of its

neighbors. The calculated pore space in the first arrangement is 47.64 percent. That in the second case is 25.95 percent. (See Fig. 5.)

It is not actually the case, however, that soil particles are of the same size in any natural soil. Consequently small particles fit in between large ones, thus decreasing greatly the actual pore space. These three cases, of which only the last may occur in nature, illustrate pore space

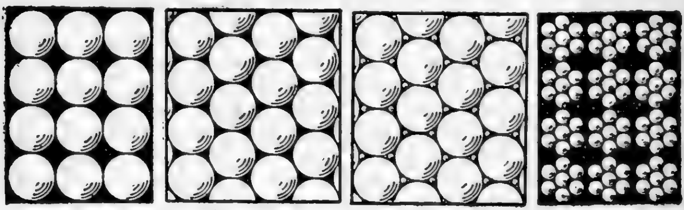


FIG. 5. — If all soil particles were spheres they could be arranged as shown above, in which case the pore space would vary in volume as explained in the text.

when the separate grain structure obtains, as in a dry sand or a puddled loam or clay.

The granular structure is the one most likely to be found in nature, although all of the particles may not be in granules. The granules being of irregular form, with many angles, there is likely to be a large amount of space between them. It would be possible under this arrangement for a soil to have a pore space of 72 percent.

The weight of a given volume of soil, including the pore space, as compared with an equal volume of water is termed the apparent specific gravity. This it will be seen is not the same as the absolute specific gravity because the amount of pore space is the important factor in determining the apparent specific gravity. Neither do the terms "light" soil and "heavy" soil bear any definite relation to the apparent specific gravity. A knowledge of the apparent specific

gravity of a soil is useful because it is an indication of the amount of pore space.

38. Relation of structure to tilth. — The term "tilth" is commonly used to denote the condition of a soil with reference to plant growth. When the physical condition of a soil is favorable to plant growth, the soil is said to be in good tilth; when the physical condition is unfavorable, it is said to be in poor tilth. A loam or clay soil to be in good tilth must have the greater number of its particles in a granular condition. The more sandy a soil the less the necessity for a highly granular structure in order that it shall be in good tilth. The greater the proportion of clay in a soil, the more necessary is the granular structure. One of the great objects in soil management is to produce and maintain the granular structure.

39. Conditions and operations that affect structure. — So far as the structure of a soil is concerned, something depends on the inherent qualities of the soil and something on its treatment by the weather and by man. These factors may be enumerated as follows: (1) texture, (2) wetting and drying, (3) freezing and thawing, (4) addition of organic matter, (5) tillage, (6) roots and animals, (7) lime.

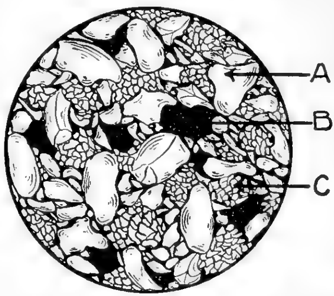


Fig. 6. — Structure of a loam soil in good tilth. (A) sand particle, (B) pore space, (C) granule composed of silt and clay particles.

40. Relation of texture to structure. — A coarse sand admits only of the separate grain structure. There is not sufficient cohesion to hold the particles in granules, and there is no plasticity. With a decrease in the size of the particles, there is a greater tendency to the formation of the granular structure, other con-

ditions being equal. This does not mean that a clay soil is easier to keep in good tilth than is a loam soil, but under favorable conditions the small particles have greater plasticity and cohesion and hence form granules more readily.

41. Wetting and drying. — As a soil becomes dry there is a contraction of volume in which process lines of cleavage or cracks occur and clods are formed. If these clods be again wetted and partly dried without working, they will separate into smaller clods and finally a granular structure will be produced. This is illustrated by the greater ease with which clods may be worked down after a rain and partial drying, than when they remain perfectly dry. Land in need of drainage is usually in poor tilth, while after drainage this condition gradually improves.

42. Freezing and thawing. — The "heaving" of roots during winter is an indication that frost has a disrupting action on the solidarity of the soil. Roots are pried out because the surface of the soil rises when freezing occurs and sinks when melting takes place. Water that is held between soil particles freezes when the temperature of the surrounding soil falls below the freezing point. As water freezes it expands, the effect of which is to force the particles farther apart. The pressure applied by the freezing water is very unevenly distributed. Around the larger water-holding spaces the particles are moved farther than are those adjacent to smaller spaces, because the larger the body of water the greater the expansion when it freezes. The uneven crowding of the particles causes a breaking up of the soil into more or less separate masses and as this proceeds with repeated freezing and thawing there is a pronounced formation of granules in a clay or loam soil.

Fall-plowed land, if left unharrowed, or if too cloddy to work down to a good tilth, will generally be mellow by spring, provided there is much freezing weather during the winter.

43. Effect of organic matter on structure. — The quantity of organic matter in a soil is frequently the deciding factor in determining its structure. Partially decomposed organic matter has a loose, spongy structure and at the same time a plastic quality. The latter causes the soil particles to cohere, and the former gives to the organic matter the property of swelling when the soil becomes wet and shrinking when it becomes dry. These changes in volume facilitate the formation of granules as previously explained.

Large areas of land in this country have deteriorated in productivity and have become compact and difficult to work on account of the gradual loss of organic matter. Naturally clay and heavy loam soils have suffered more in this way than have lighter soils. Where marked decrease in crop returns has occurred during the time that soils have been under cultivation, the difficulty can generally be traced to loss of organic matter more than to any other factor in plant growth. Compact soil, with consequent poor tilth, is one of the most common conditions in poor farming regions, and is usually associated with a low content of organic matter.

44. Roots and animals. — In some way not very well understood roots exert more or less influence on soil structure. Shallow, fibrous-rooted plants, among which are the grasses, wheat, barley, millet and buckwheat, have the most favorable action in granulating soil. More deeply rooted, and especially tap-rooted plants, have this property to a less extent. In fact, a crop of beets may help to compact a soil already in bad condition. In establishing a rotation it is desirable that some fibrous-rooted plants form one or more of the courses.

Various forms of animal life help to granulate soils. Of these, earthworms are the most notable. The soil particles that they excrete from the digestive tract may amount to

several tons in an acre in the course of a year, while their burrows ramify through the soil in all directions. The movement of soil particles that results is an appreciable factor in changing soil structure. Insects and other burrowing creatures affect soil structure in a similar way.

45. Tillage and structure. — The ordinary operations of tillage are designed to improve soil structure, and are effective if these operations are conducted at the proper time and in the best way. Plowing, which is the most fundamental of all tillage operations, may improve soil structure or may injure it, depending on the condition of the soil at the time of plowing. It is a matter of common knowledge that working a soil saturated with water will cause it to puddle, or in other words, to assume the separate grain structure. Plowing when the soil is very dry may have the same effect, although not usually to the same extent. However, when a soil is moderately moist, plowing aids greatly in effecting a granular structure. This it does by the peculiar twisting action that the curved moldboard gives to the furrow slice. The soil in immediate contact with the plow surface is retarded by friction, and the layers above tend to slide over one another much as do the leaves of a book when they are bent. The soil is thus broken up into masses of aggregates corresponding to the location of the lines of weakness. If a soil has been strongly compacted, so that there are few lines of weakness, the clods will be large when the soil is plowed. Plowing helps to improve the tilth of the soil, but it will not overcome entirely a bad physical condition.

46. Structure as affected by lime. — One of the properties possessed by lime is that of flocculating clay. This may be readily observed by stirring a spoonful of clay in a tumbler of water and then adding a quarter of a spoonful of burnt lime. It will be noticed that the soil settles much more quickly after the lime has been added than before. Sandy

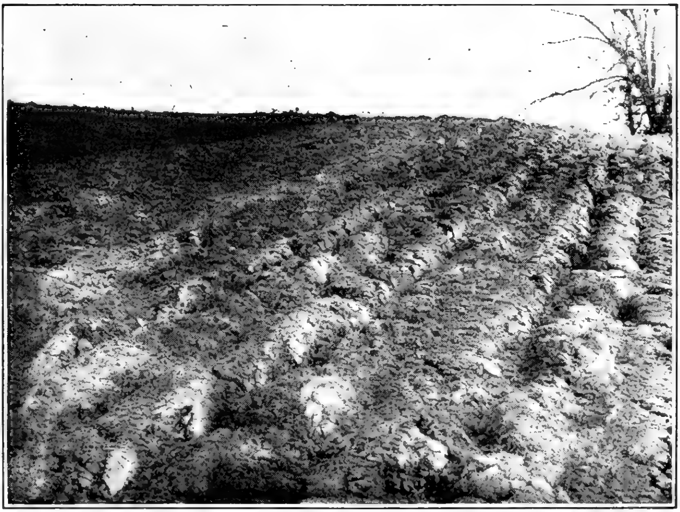


Plate VII. Tillage. — Good tilth is a response to good soil management. The upper figure is an illustration of poor, the lower of good, tilth.

soils are not flocculated to the same extent by lime, but are thus affected in proportion to the quantity of clay they possess.

Of the different forms of lime, quick-lime and water-slacked lime are more active in producing a granulated structure of soil than is ground limestone, marl or air-slacked lime. This is one reason why the burned lime is superior to ground limestone for use on heavy clay soils, on which there may be a pronounced difference in the effect of the two kinds of lime on crop production. Warington reports a statement of an English farmer to the effect that by the use of large quantities of lime on heavy clay soil he was enabled to plow with two horses, while three were necessary before applying lime.

47. The soil survey. — The purpose of a soil survey is to classify and map the soils in a given area according to their crop relations and their physical properties, and to correlate these soils with those in other areas. The soil unit, or what may be termed the soil individual, is the type, and on a soil map each type is given a different color. Every soil type has a certain peculiar and characteristic appearance and certain inherent properties that distinguish it from every other type. When the type is known some practical information regarding its texture and its amenability to tillage and to drainage may be predicted, and something in regard to its productiveness and the crops to which it is adapted may also often be inferred.

48. Classification of soils. — In order to distinguish between soils, and to give a basis on which to separate them into the types to which reference has been made, a form of classification has been adopted in this country that takes into consideration much of what is known of their history and their properties. Thus the first large division into which a soil falls is known as the soil province, which is based, in a general way, on the process of formation. A

province may represent residual soil, like the Piedmont province, or glacial soil, or marine soil, or soils of other processes of formation.

The next smaller division is the series. A soil series has been defined as " a group of soils having the same range in color, the same character of subsoil, particularly as regards color and structure, broadly the same type of relief (topography) and drainage, and a common or similar origin." The last of these properties is due to the fact that soils of the same series must fall within the same province.

The final division is the class, which has been described in paragraph 33. A soil class is not limited in its occurrence to a soil province, but the same class may be found in all provinces. In this respect it differs from a series, any one of which occurs only in a single province.

A soil type represents a soil of a single province, a single series and a single class, and represents the features of each. The following is an example:

Province	Piedmont
Series	Cecil
Class	Clay
Type	Cecil clay

49. Information furnished by a soil survey. — The method of arriving at the identification of a soil type involves a history of the soil, and that may tell something about its probable chemical composition, as may be judged from the tables of analyses of soils of different formations (§§ 18–28). The series we have already found to signify something in regard to the working qualities of the soil, as does also the class. These distinguishing features are much more marked in some types than in others; in the case of certain types considerable definite information is available when the soil type is known, while in the case of others less knowledge is afforded. Some types always represent a defective soil due

perhaps to lack of lime, or poor drainage, or they may be characteristically deficient in phosphoric acid or even in potash. Again a type is often indicative of the kind of crops to which a soil is adapted, but as climate is a large factor in determining the success of any crop, conclusions of this nature are not of universal application. The working qualities of a soil may usually be gauged with some degree of certainty when the type is known. It is, however, as a foundation for a further study of soils that the survey is probably of greatest usefulness.

QUESTIONS

1. To what does the term "texture" refer when used with reference to soils?
2. Name the groups into which soils are divided by a mechanical analysis.
3. What characterizes the difference in mechanical composition of soils adapted respectively to wheat, corn and potatoes?
4. What is meant by class as applied to soils?
5. In what class does soil belong that contains 20 percent clay and 20 percent silt? One that contains 40 percent clay and 30 percent silt? One that contains 25 percent clay and 35 percent silt?
6. How do soils containing a high percentage of clay or silt behave when wet? How is their water capacity likely to compare with that of a soil high in sand?
7. How do coarse and fine particles usually differ with respect to their content of phosphoric acid, potash and lime?
8. What is meant by soil structure?
9. Distinguish between separate grain structure and granular structure. Which permits of the greater amount of pore space?
10. Describe the relation of tilth to structure.
11. Explain relation of structure to texture.
12. Explain relation of structure to wetting and drying of soil.
13. Explain relation of structure to freezing and thawing of soil.
14. Explain relation of structure to organic matter.
15. Explain relation of structure to roots and animals.
16. How is structure affected by lime?
17. How is structure affected by tillage?

LABORATORY EXERCISES

EXERCISE I. — Examination of soil particles.

Materials. — Samples of soil, hand lens, high power microscope.

Procedure. — Examine various sizes of soil particles under the hand lens and later under the microscope. Observe shape and color. If possible measure size of particles. Try to distinguish between silt, clay and sand particles.

EXERCISE II. — Examination of soil separates.

Materials. — The seven separates into which a soil is divided in making a mechanical analysis.

Procedure. — As a soil is made up of the seven grades of particles in varying amounts, the characteristics of the grades will determine the characteristics of the soil.

Observe the cohesion and plasticity of each grade. The finer grades are usually richer in plant food. Therefore try to imagine the physical and chemical properties of different mixtures. Study the separates with a view to identification if presented unlabeled.

EXERCISE III. — Simple mechanical analysis.

Materials. — Sandy loam well pulverized, 8 oz. bottle, funnel with filter paper, torsion balance, ammonia. (See Fig. 7.)

Procedure. — Place 50 grams of a dry and well-pulverized sandy loam in a bottle of about 8 ounces capacity. Add a few drops of ammonia and fill two-thirds full of water. Shake five minutes to break up all granules. Then allow sample to stand until the various grades of sand have settled to the bottom, after which decant the silt and clay. Add water and repeat this until the water clears as soon as the sands have settled. Then wash the sands out into a weighed filter paper held in a funnel. Allow sands to drain. Then dry sands and filter paper thoroughly and weigh. This weight, less the weight of the filter, will give the weight of the sands. Fifty grams, less the weight of the sands, will give the weight of the silt and clay. Calculate the percentages of sand and of silt and clay respectively in the sample of sandy loam.

EXERCISE IV. — Study of soil class and its determination by examination.

Materials. — Hand lens, a number of different soil classes (sand, sandy loam, clay loam, loam, silt loam, muck, etc.) labeled for study and a set of unknown specimens for identification.

Procedure. — Examine the texture of each of the labeled soils both under the hand lens and by the feel. Observe the color and estimate the amounts of organic matter by the darkness of the color. Be able to identify samples if unlabeled.

Observe the plasticity and cohesion of each soil when enough water has been added to develop maximum plasticity. Make small marbles of sand, clay and muck respectively when each is at its maximum plasticity. Dry and observe relative cohesion and plasticity. Be able to state the relation of texture, moisture and organic matter to cohesion and plasticity. What is the practical importance of texture and class?

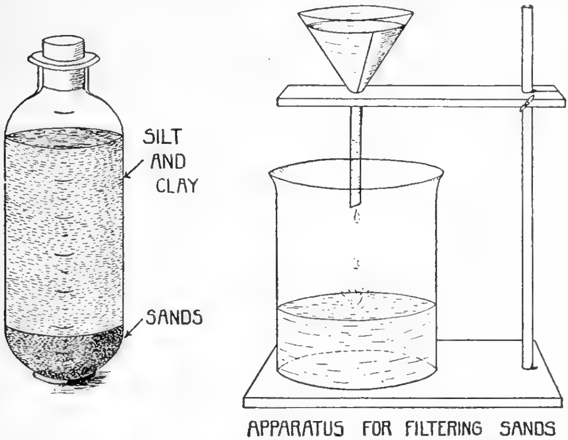


Fig. 7. — Apparatus for a simple mechanical analysis of soil. Shaker bottle, funnel, filter, beaker and stand.

Obtain set of unlabeled samples for identification of class. If possible, pupils should also identify samples in the field. As moisture variations and tillage operations often make great differences in the general appearance of a soil, skill in quickly and accurately determining the class of any soil in the field is a valuable asset in all agricultural work.

Exercise V. — Determination of soil class from a mechanical analysis.

Materials. — Figure on page 35.

Procedure. — By the use of the chart determine the class of the following soils and describe their probable characteristics.

Soil	Fine Gravel	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt	Clay
1	1	5	6	5	3	70	10
2	2	3	10	18	12	45	10
3	1	2	14	18	25	30	10
4	2	3	25	14	16	30	10
5	3	7	25	30	20	10	5
6	2	3	12	19	24	10	30
7	1	4	9	11	10	40	25
8	2	2	3	4	4	60	25
9	1	2	7	6	4	20	60
10	2	1	3	2	2	50	40

Be ready to explain the practical value of a mechanical analysis.

Exercise VI. — Soil structure.

Materials. — Puddled and granular soils.

Procedure. — Examine under hand lens a granular and a puddled soil. Describe each and make drawings. Discuss each as to probable relation to air and water movement, penetration of plant roots, ease of making seed bed, etc. Be ready to suggest practicable remedies for poor structure.

Exercise VII. — Determination of apparent specific gravity of a dry sand and clay. (See Fig. 8.)

Materials. — Torsion balance, dry soils and a 100 c.c. graduated cylinder.

Procedure. — Apparent specific gravity is the weight of dry soil compared to the weight of the same volume of water.

Weigh the 100 c.c. graduate in grams, then fill to the 100 c.c. mark with loose sand. Weigh and calculate the weight of the sand in grams. The weight of the sand divided by 100 (the weight of 100 c.c. of water in grams) will give the apparent specific gravity of the loose sand. Now compact the sand as much as possible by jarring and read volume. Divide the weight of the sand by this volume to obtain the apparent specific gravity of the sand compact.

Determine in the same way the apparent specific gravity of the clay when loose and when compact.

Compare the figures from each soil and explain the reasons for the differences observed.

Calculate the weight per cubic foot and acre foot of the sand and clay when loose and when compact.

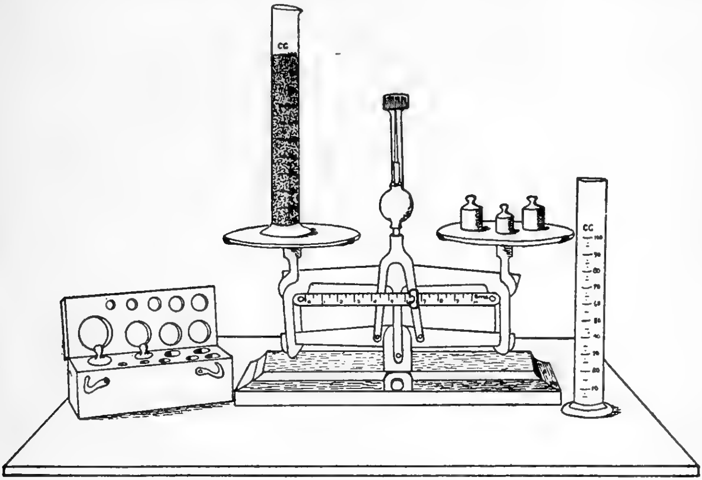


FIG. 8. — Equipment for the determination of the apparent specific gravity of soil, consisting of a balance, a set of weights and a 100 c.c. graduated cylinder.

EXERCISE VIII. — Calculation of pore space.

Materials. — Data from Exercise VII.

Procedure. — Using 2.7 as the absolute specific gravity of soils and the data from the preceding exercise, calculate the pore space on loose and compact clay and sand respectively by means of the following formula.

$$\%\ \text{pore space} = 100 - \left[\frac{\text{ap. sp. gr.}}{\text{abs. sp. gr.}} \times \frac{100}{1}\right]$$ [1]

Be ready to explain the reasons and significance of the results obtained.

[1] Ap. sp. gr. means apparent specific gravity. Abs. sp. gr. means absolute specific gravity.

EXERCISE IX. — A study of the plow.

Material. — Garden plow and team.

Procedure. — Study the plow by following the diagram in Fig. 9. Locate the mold board, point, share, landside, shin, heel beam, coulter and clevis.

Adjust the plow to various widths and depths of furrow slice, trying out each adjustment by throwing several furrows. Be sure that with each adjustment the plow operates properly.

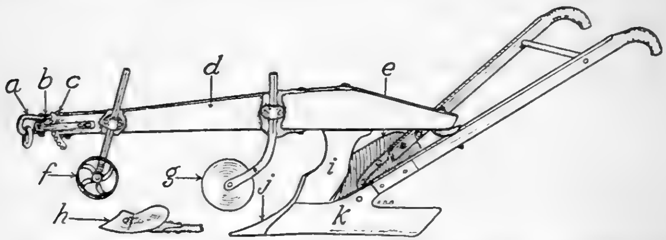


FIG. 9. — A walking plow and its attachments. (*a*) clevis, (*b*) beam clevis, (*c*) bridle, (*d*) beam, (*e*) mold board, (*f*) depth wheel, (*g*) rolling coulter, (*h*) jointer, (*i*) standard, (*j*) share point, shin above, (*k*) landside.

Study the inversion of the furrow slice and be ready to explain how and why a plow is a good pulverizing agent. The pupils should hold the plow as much as possible in the various tests.

If a sod plow is available, a study of this form would be of value, comparing it with the garden plow above. A comparison of a walking plow with a sulky plow would also be worth while.

A visit to an implement dealer for the purpose of looking over the various makes of plows might be a profitable exercise. The manufacturer's and the dealer's viewpoint is as valuable as that of the farmer.

CHAPTER V

ORGANIC MATTER

A VERY important constituent of soil is the more or less decomposed organic matter that has become incorporated with it. Organic matter is found in larger quantity in surface-soil than in subsoil because it comes largely from vegetable matter that has fallen on the surface and there decayed, or that has been plowed under. Animal remains and lower forms of plant life also contribute to the supply. The roots of dead plants are one source of organic matter, and as these generally penetrate into the subsoil they deposit a limited quantity of organic matter in that part of the soil.

50. Classes of organic matter. — Organic matter that is incorporated with soil gradually decomposes, forming substances that are very different in their properties from the original material. The process may be roughly divided according to the degree of decomposition into three classes, viz: (1) undecomposed matter, (2) partially decomposed matter, (3) final products. The substances representing each of the stages in the process have different properties and differ in their effect on soil.

Undecomposed organic matter is of use in making less compact a heavy soil; on the other hand, it may make too loose a naturally light soil and may cause it to dry out to such an extent that its productiveness will be curtailed. For instance, a stand of oat stubble or of corn stalks that would be of much benefit to a heavy soil in a humid region might injure seriously a light soil in a semi-arid region.

Partially decomposed organic matter is of benefit to soils in a number of ways and it may also be injurious. These properties will be discussed later. The term "humus" has been somewhat loosely used with reference to the substances of this class. It will not be used in this book. Organic substances represent a wide range of intermediate products of decomposition. They profoundly affect the properties of soils and are always present in arable soils.

Final products of decomposition of organic matter are water and gases. The latter may unite with some of the inorganic matter of the soil to form purely inorganic substances, and these are as a rule readily available to plants. They differ from the substances of the other two classes in that none of them is injurious to crop production.

51. Beneficial effects of organic matter. — There are many ways in which organic matter may benefit soils, either directly or indirectly. Soils differ somewhat in the effect that organic matter may have on some of their properties. An example of this has been cited in the effect of organic matter on a heavy soil in a humid region as compared with its results in a light soil in a semi-arid region. Another example is to be found in the results that follow the plowing under of green-manures. In some soils and under certain conditions this may be temporarily injurious, although it is usually a very beneficial practice.

An enumeration of the beneficial effects of organic matter in soil is necessarily open to criticism on account of the different responses of different soils, but with some modifications the following will hold.

(1) It increases the tendency towards the formation of granular structure.

(2) On account of the porous nature of organic matter the pore space of the soil is increased and aëration improved.

(3) It increases the water-holding capacity of soils.

(4) It improves drainage by reason of the properties stated under (1) and (2).

(5) It increases the extent of root growth for the same reasons.

(6) By making the soil darker, it facilitates heat absorption.

(7) It is a source of plant-food material.

(8) It furnishes energy for the growth of bacteria.

(9) Its decomposition produces carbonic acid gas and other acids that help to render plant-food materials soluble.

52. Porosity of organic matter. — The way in which organic matter promotes a granular structure in soils has already been described, as has also the relation of soil structure to tilth. In addition to this effect on soils, organic matter also serves to make soil more porous by reason of its own porosity. It may be compared to a sponge in its ability to hold air or water. A peat soil, for instance, will hold more water than its own weight of dry matter. Organic matter extracted from a peat soil was found to carry twelve times its own weight of water. It may readily be seen that the porous nature of this organic matter may greatly increase the water-holding capacity of a soil. At the same time it may increase the capacity of the soil for air.

53. Organic matter and drainage. — By reason of the greater porosity due to the presence of organic matter, the movement of water through soils is facilitated and thus the soil is better drained. The advantages of good drainage will be discussed more fully later, but an important one of these is a greater growth of roots, which increases their opportunity for securing food and thus increases the size of crop.

54. Organic matter and soil color. — Partly decomposed organic matter generally gives a dark color to a soil. A dark soil absorbs heat more readily than does a light-colored

one, and as warmth is an important factor in plant growth, especially in the spring, a dark soil usually has an advantage over a light-colored one.

55. Organic matter a carrier of plant-food material. — In its relation to the supply of plant-food material, organic matter is the storehouse in which nitrogen is held in a form in which it cannot be leached from the soil in large amounts and yet from which it gradually becomes available to plants. Certain inorganic plant nutrients are likewise held in such condition that they readily become useful to plants. In the process of rotting, combinations are formed between organic matter and certain inorganic plant nutrients, removing the latter from the very insoluble minerals of the soil. On further decomposition the inorganic substances are left in a form readily usable by plants.

56. Organic matter and nitrogen. — The relation of organic matter to the nitrogen supply is of particular interest because it is as organic matter that practically the entire supply of nitrogen enters the soil. All soil nitrogen has been secured from the air and the process is still going on. This is done largely by the lower forms of plant life known as bacteria, fungi and molds. These organisms living in the soil, or in the roots of higher plants, feed on the non-nitrogenous organic matter of the soil and plants, and upon the nitrogen of the atmosphere that passes into the pores of the soil. The non-nitrogenous organic matter and the atmospheric nitrogen are thus combined to form the tissues of these lower plants, which soon die and finally add to the soil the nitrogen they have accumulated.

57. Organic matter and soil microörganisms. — We have just seen how the nitrogen-fixing organisms use non-nitrogenous organic matter in their growth. They use it as a source of energy, as do animals. Many other forms of lower plant life use organic matter, both nitrogenous and non-

nitrogenous. As the growth of these organisms is very necessary in making the various sorts of plant nutrients available, the supply of organic matter for this purpose is of great importance.

58. Organic matter forms acids. — Finally, organic matter in its very last stages of decomposition continues to serve the plant by producing carbonic acid gas, which, dissolved in soil water, is an excellent solvent for many mineral substances needed by plants. It is estimated that in an acre of soil sixteen inches deep, sixty-eight pounds of carbon dioxide are produced annually from the decomposition of organic matter when present in ordinary quantity. There are also other organic acids formed by the rotting of organic matter that serve to dissolve the inorganic matter of soils. The combinations of these organic acids with mineral substances form readily available plant-food materials. Another final product of nitrogenous organic matter is nitrate, which is the most available form of nitrogen for many plants.

59. Injurious effect of organic matter. — The injury that organic matter may cause is probably not of very frequent occurrence and is unimportant as compared with its beneficial action. Two effects have been noted:

(1) Undecomposed organic matter may cause a soil to dry out quickly by preventing it from settling sufficiently to establish water connection with the subsoil and by leaving large air spaces that allow a rapid movement of air through them which dries out the soil.

(2) Partially decomposed organic matter may form products that are poisonous to some agricultural plants or that interfere with the operations of those microörganisms that are beneficial to plant growth.

60. Management of s il with respect to organic matter. — The first step in the control of organic matter in soil is to

bring about decomposition, which operation is performed by bacteria, fungi and molds. It has already been pointed out that unrotted organic matter has very little useful-

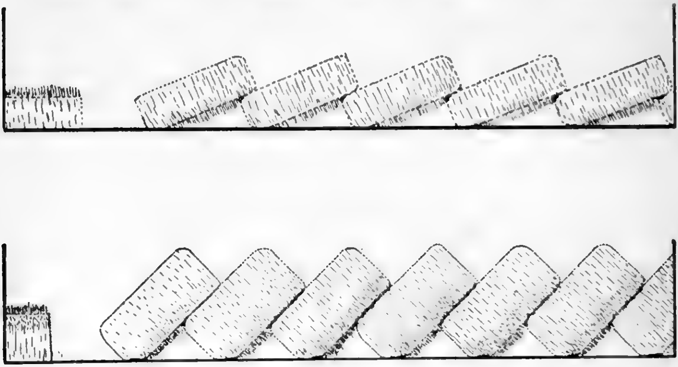


FIG. 10. — The upper figure represents a furrow slice laid too flat for the most rapid decay of organic matter when present in large quantity. The lower illustration shows a better furrow angle.

ness and may be injurious. The conditions that favor the rapid and desirable rotting of organic matter are the following:

(1) An amount of moisture that will not fill all of the pore spaces, but that will provide water required by the organisms that decompose the organic matter. The soil moisture content most favorable for plant growth is about the same as that most favorable for rotting organic matter.

(2) The soil should be loose enough to allow air to penetrate readily, but not so loose as to leave large air spaces. Air is necessary to the activity of those organisms that produce a desirable kind of decomposition. A compact soil, or a very wet soil delays the rotting process and favors the growth of organisms that form products poisonous to agricultural plants.

(3) The soil should not lack lime, as the presence of lime in a readily soluble form favors the development of many forms of life that decompose organic matter, and it also prevents the poisonous action of certain substances produced in the process.

61. Sources of organic matter. — In addition to the natural supply of organic matter referred to in the first part of this chapter, there are other sources from which the farmer may obtain a supply by outright purchase or by means of their production on the farm. Among these are farm manure, grass and clover sod, green-manures, peat and muck, crop residues, like straw, cornstalks and leaves, dead animals, certain commercial products, like cottonseed meal and dried blood, and finally weeds, which are sometimes used for that purpose in orchards.

These various materials and their use in contributing to the supply of organic matter in soils will be discussed later under the respective heads (1) farm manure, (2) green-manures and (3) commercial fertilizers.

QUESTIONS

1. Into what three classes may the organic matter of the soil be divided ?
2. What is the effect of organic matter on the water-holding capacity of soil ?
3. What is the effect of organic matter on drainage ?
4. How does organic matter contribute to the availability of plant nutrients in soils ?
5. In what general way does organic matter affect the growth of bacteria in soils ?
6. How do the final products in the decomposition of organic matter increase the availability of plant-food materials in soil ?
7. In what two ways may organic matter be injurious to soils ?
8. What are the soil conditions that favor a rapid and desirable decomposition of organic matter ?
9. Name the sources of organic matter that may serve to increase the supply in soils.

LABORATORY EXERCISES

Exercise I. — Examination of soil for organic matter.

Materials. — Samples of clay soils respectively low and high in organic matter, hand lens, flame.

Procedure. — Examine a soil rich in organic matter under the hand lens. Observe character of the organic matter, its color and its effect on structure. Compare the structure of the soils high and low in organic matter. What effect does the organic matter appear to have upon granulation? How should the organic matter influence the ease of preparing a seed bed? How does organic matter influence percolation of water through a soil? How does it affect its water capacity?

Place a small portion of the soil rich in organic matter in the flame. Observe and explain the results.

Exercise II. — Examination of peat and muck.

Materials. — Samples of peat and muck, hand lens, flame.

Procedure. — Examine samples under lens and describe and make drawings. What is the origin of the materials, their structure, composition and degree of decay? What is the value of peat and muck?

Place a small portion of each in the flame. Observe and explain results. What is shown regarding the composition of peat and muck?

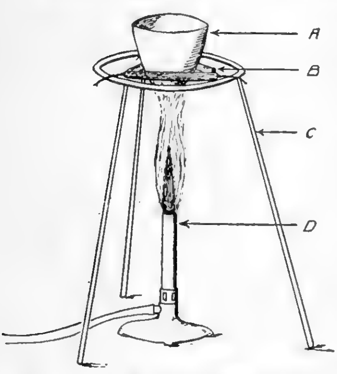


Fig. 11. — Apparatus for the estimation of organic matter in soil. (A) crucible, (B) clay covered triangle, (C) tripod, (D) Bunsen burner.

Exercise III. — Estimation of organic matter.

Materials. — Soil samples, crucible, stirring wire, flame, tripod, clay triangle, balance.

Procedure. — Place a five-gram sample of dry soil in a weighed crucible. Ignite with frequent stirrings at a low red heat over a flame until original dark color has disappeared. Cool and weigh. The loss has been largely organic matter. Calculate the percentage based on the original sample. Find in this way the percentage of organic matter present in several different soils.

EXERCISE IV. — Extraction of partly decomposed organic matter.

Materials. — Muck, dilute hydrochloric acid, ammonia, hydrate of lime, filter paper and funnel.

Procedure. — Place about a gram of moist muck on a filter paper in a funnel. Treat the muck with a few drops of dilute hydrochloric acid. Wash out the acid with 50 c.c. of distilled water. Discard this percolation. Now treat the soil with ammonia. After allowing it to stand a few minutes wash with distilled water and catch percolate.

The percolate should be black, showing the presence of partly decomposed organic matter. This is the material seen escaping from manure piles. It is the most valuable portion of the organic matter.

Treat a portion of this soluble organic matter with hydrate of lime. Note the flocculating effect, which prevents the leaching of organic matter from the soil.

EXERCISE V. — Influence of organic matter on rate of percolation of water through soils.

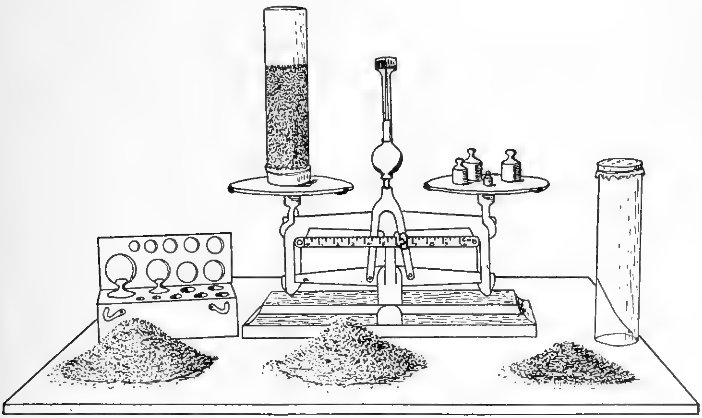


FIG. 12. — Apparatus for studying the influence of the addition of organic matter to a soil on the rate of percolation and percentage of water holding capacity.

Materials. — Clay or clay loam soil finely pulverized, moist muck, lamp chimneys, torsion balance and weights, cheesecloth.

Procedure. — Divide the soil in two portions. To one add 10 per cent of the moist muck. Mix thoroughly. Place equal and definite

weights of the two portions of soil in respective lamp chimneys, having previously tied cheesecloth neatly over the bottoms to keep the soil in place and yet to allow drainage. Compact the soils to uniform height. Weigh each chimney plus its portion of soil. Set the chimneys in such a position as to allow free drainage. Pour equal amounts of water on each and observe the rate of percolation of the water through the two soils. Explain results and show the practical bearing of the experiment.

Exercise VI. — Influence of organic matter on percentage of moisture held in soil.

Materials. — Same as Exercise V.

Procedure. — After observing the rate of percolation in the above exercise, saturate the soils, and allow them to drain freely until all gravity water has disappeared. Now weigh each chimney plus its soil. The increased weight over that of the original sample is water retained. Calculate the percentage of water thus retained, based on the weight of the original dry sample. Explain the practical importance of the results.

CHAPTER VI

SOIL WATER

Of the great number of factors that influence the growth of crops none is of more importance, or possibly of as much importance, in its effect on the yield of crops as water. A soil may contain too much water for the best growth of crops, or it may have too little. On the one hand, we approach swamp conditions, and on the other the desert state. Even in the same locality and with equal rainfall one field may have too much moisture and another too little. While the volume of water contained in a soil depends more or less on the rainfall, it is not controlled entirely by it; for within a wide range of atmospheric precipitation soils of the same type may not vary greatly in their moisture content. This is because there are other factors beside rainfall that serve to regulate the supply of soil water.

62. Forms of water in soils. — It has already been pointed out that in every soil there are spaces between the particles, or aggregates of particles and that the size and total volume of these spaces vary with different soils. These spaces may be completely filled with water or they may be nearly empty. When the pore spaces are entirely filled with water, three forms of water are found to be present: (1) hygroscopic, (2) capillary and (3) free or gravitational. These forms differ in their relation to the soil particles.

63. How the three forms of water differ. — No soil in a natural state, that is as it exists in the fields or woods, is ever perfectly dry. No matter how small the rainfall or how

parched the crops, there is always a thin film of moisture surrounding each particle or aggregation of particles, although plants may not be able to obtain it. The thin film that is absorbed from the air and condensed on the surfaces of the particles, when no other source of supply is at hand, is termed hygroscopic water. If the film becomes somewhat thicker by reason of another supply like rainfall or underground water, the additional supply is termed capillary water. These two forms are much alike, both being held as a film around the particles, partly by the attraction of the soil for the water and partly by the attraction of the particles of the water for each other, which prevents the film from breaking and running away. One other difference between hygroscopic water and capillary water is that the former is always stationary, while the latter may move.

A further increase in the quantity of water in a soil gives rise to the third form — gravitational or free water. With the advent of more water, the films become so thick that the attraction by which they adhered to the particles is overcome by gravity and there is a downward movement through the pore spaces, or else the pore spaces are completely filled and the soil becomes saturated by reason of the inability of the water to escape from the soil.

64. Hygroscopic water. — From a practical viewpoint, hygroscopic water is not of much importance because plants cannot use it. A plant may die for want of water when the soil in which it grows contains its maximum of hygroscopic moisture. The forces that hold the water in the soil are greater than those that tend to draw it into the plant.

The quantity of hygroscopic moisture that a soil will hold depends largely on its texture and on the quantity of partially decomposed organic matter that it contains. Fine particles have a greater absorptive power for water than do

coarse ones. Clay has a large absorptive capacity and the presence of certain compounds increases immensely the content of hygroscopic moisture.

65. Capillary water. — The essential difference between capillary water and hygroscopic water is that the former is capable of motion and most of it may be used by plants. The fact that the capillary film is thicker causes it to be less firmly held by the soil particles, in consequence of which the water near the outer surface of the film can move in response to certain forces, and the absorptive action of roots is sufficient to withdraw it, until the film becomes so thin that very little except hygroscopic water remains. The difference between hygroscopic water and capillary water is illustrated in Fig. 13.

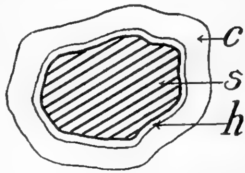


Fig. 13. — Diagrammatic drawing of soil particle and surrounding films of hygroscopic and capillary water. (*s*) soil particle, (*h*) hygroscopic film, (*c*) capillary film.

66. Capillary water capacity. — Comparatively large quantities of water may be held in soils by capillarity. In fact by far the major portion of water used by crops is obtained from the capillary form. The quantity present varies with different soils and at different times in the same soil. The conditions that tend to increase the capillary moisture content of soil are the following:

1. A fine-grained texture, or in other words a large proportion of small particles. Thus in a test of a fine sand, a sandy loam and a clay soil they were found to contain respectively 10, 15 and 20 percent of capillary water in addition to the hygroscopic water.

2. A soil structure that gives a maximum effective surface exposure within the soil. For this reason the granulation of a clay soil, or the compacting of a coarse sand will cause a rise in its capillary capacity.

3. A large amount of partially decomposed organic matter. Thus a muck soil may contain a greater weight of capillary water than the weight of the dry soil itself. Farm manure or green-manures are valuable for this purpose.

4. A low soil temperature, if it is above the freezing point.

5. A strong soil solution, such as is produced by proper manuring and good tillage.

6. The absence of oily material produced by decay of organic matter.

The conditions that are favorable to a large crop production are, in general, helpful in increasing the capillary water capacity of a soil. The effect of temperature, and of oily material formed by decay of organic matter, are exceptions to this. Much may be done by tillage, drainage and manuring to increase capillary water capacity.

67. Movement of capillary water. — The movement of capillary water is from particle to particle within the water film, the film being continuous from one particle to the other. The movement is always from the thicker part of the film to the thinner part, because there is a tendency for the film to assume the same thickness throughout. Capillary movement may, therefore, be upward or downward or lateral. Following a shower of rain the movement is downward, as there is more moisture at the surface than below. Generally the movement during the growing season is from the lower soil towards the surface, because the roots and surface evaporation continually remove water from the upper part of the soil and this is replenished from the wetter soil below. The lateral movement is usually slight. The factors that determine the rate of movement of capillary water are much the same as those that influence its quantity. They are (1) texture, (2) structure, (3) height of water column, and to a less extent the other factors that influence the quantity of capillary water.

68. Effect of texture on capillary movement. — The finer the texture of a soil, other things being equal, the slower is the movement of capillary water, but the water will eventually rise higher in the soil of fine texture. This is illustrated by the experimental data contained in the following table:

TABLE 12. — EFFECT OF TEXTURE ON RATE AND HEIGHT OF CAPILLARY RISE FROM A WATER TABLE THROUGH DRY SOIL

SOIL	1 HOUR	1 DAY	2 DAYS	3 DAYS	4 DAYS	5 DAYS
	inches	inches	inches	inches	inches	inches
Sand	3.5	5.0	5.9	6.8	6.8	6.9
Clay	.5	5.7	8.9	10.9	12.2	13.3
Silt	2.5	14.5	20.6	24.2	26.2	27.4

One can see from the above data that although water rises most rapidly in the sand, it does not rise as high as in the other soils. This experiment was not continued long enough to obtain the maximum rise in clay. Some experimenters have been able to obtain a rise of water to a height of twenty-six feet in a clay soil.

69. Effect of structure on capillary movement. — Soil structure by affecting the size of the pore spaces also affects the rate of capillary movement. In general the condition most favorable for plant growth is also best adapted to capillary movement. Good tillage, tile drainage, farm manure and lime all help to hasten the movement of water in a soil. A very loose soil does not admit of capillary movement and consequently cultivation of the surface prevents water from coming to the surface of the ground from whence it escapes into the air. Rolling, or otherwise compacting the soil aids capillary movement and thus causes loss of moisture from the surface soil.

70. Height of water column and capillary movement. — Gravity opposes the upward movement of water and consequently the higher water rises the more slowly it moves. This has been demonstrated by measuring the quantity of water that evaporated from the surface of columns of sand of different heights, the rate of loss by evaporation indicating the degree of rapidity of movement.

Table 13. — Evaporation from the Surface of Sand Columns of Different Heights, their Bases being in Contact with Free Water

Height of Column in Inches	Daily Evaporation at Surface in Pounds per Acre
6	25,872
12	25,191
18	18,155
24	7,716
30	4,312

This has a practical significance in dry weather when the moisture supply for plants is drawn largely from the water stored in the lower soil. The lower the water level becomes, the more slowly does the moisture rise to the surface soil where are to be found the larger part of the roots of many plants. Fortunately, however, as the soil dries out, the roots go somewhat deeper, so that they in part overcome this difficulty.

71. Gravitational water. — It has already been said that gravitational, or free water, is the water in excess of the capillary water and is constantly moving downward, thus preventing the soil from becoming saturated owing to the inability of the water to escape. It is very desirable that the gravitational water shall not remain in that part of the soil in which plants have their roots. A saturated condition of the surface soil is very injurious to most agricultural plants. In this respect there is a great difference

between gravitational water and capillary water, and while it is desirable to have as much capillary water as possible in the soil at all times, it is equally important that the gravitational water shall be removed.

The factors that determine the rate of flow of gravitational water in soil are texture, structure, and cracks and openings produced by freezing, by drying, by roots and by the burrowing of sundry forms of animal life, like worms and insects. Another, and very important factor, is the means for the escape of water from the subsoil, since without that a soil will become saturated no matter how favorable the conditions may be for escape of water from the surface soil. For this purpose tile drainage must often be used.

A sandy soil allows the escape of gravitational water more rapidly than does a loam or clay soil. Soil in good tilth is better in this respect than is compact soil. It is better that water should run through a soil than that it should run off the surface. The latter generally causes erosion with the loss of much good soil, and may leave the subsoil too dry. For this reason a loam or clay soil should always have a loose surface when no crop is on the ground.

72. The water table. — The gravitational water that passes through the ground accumulates, in humid regions, in the lower depths of soil, or possibly in underlying sand or gravel, which it saturates. The surface of this mass of water is called the water table, the depth of which below the surface of the ground varies from a few inches to a great many feet, depending on the opportunity it has to escape. This is the water that furnishes the supply for shallow wells and for springs. In some places the water table is sufficiently near the surface to be of use to plants owing to its capillary rise during dry periods.

73. Relations of soil water to plants. — The quantities and movements of the several forms of water in soils are of

the greatest importance in the growth of plants. There are certain more or less definite relations that obtain, so that for any given condition of the water supply certain results in crop growth may be expected. As we shall see later, these conditions of water supply are, within certain limits, subject to the control of man and consequently the growth of crops may be regulated to some extent by these means.

74. Ways in which water is useful to plants. — In many indirect ways water contributes to plant growth, as for instance in aiding in the disintegration of rocks, in the promotion of decay of organic matter and in numerous other ways, but it is with the use of water as it occurs in soils and as taken up by plants that we are now concerned. The functions that water thus serves may be listed as follows:

1. Water is a direct source of food material, for it either becomes a part of the plant substances without change (about 90 percent of most plants is water), or it is decomposed and its elements are used in building plant tissue.

2. Water acts as a solvent and carrier of plant-food materials, taking up these substances in the soil and transferring them to the plant, where they are utilized in the formation of plant tissue.

3. Water in the plant serves to keep the cells expanded, to regulate the temperature and to carry in solution substances from those portions of the plant in which they are formed, to the places where they are needed, as for instance, to transport soluble matter from the leaves of the potato, where the starch is formed, to the tuber, where it is stored.

75. Water requirements of plants. — Most of the water that enters the roots passes on through the plant and evaporates from openings in the leaves. A large crop will, other things being equal, require more water for its production than a small crop. The ratio of the quantity of water used, to the quantity of dry matter that the plants contain, is

called the transpiration ratio, because the water given off by the leaves of the plants is said to be transpired. The quantity of water required to produce a pound of dry matter varies from 200 to 500 pounds in humid regions to almost twice that amount in arid regions. There are a number of factors that influence the transpiration ratio. Among these are the following:

1. The kind of plant.
2. The quantity of water in the soil.
3. The humidity, wind and temperature of the air.
4. The natural fertility and manurial treatment of the soil.

76. Transpiration by different crops. — Some kinds of plants require much more water to produce a pound of dry matter than do others. Oats, rye, peas and potatoes are crops that have a high transpiration ratio. Wheat and barley have medium ratios and corn and millet low ratios. This, in a way, is a guide to the adaptability of these crops to growth on dry soils.

77. Effect of soil moisture on transpiration. — An increase in the water content of any soil usually results in an increased transpiration ratio for any crop grown on it. This is well brought out by an experiment in which corn was grown in soil contained in pots to which different quantities of water were added and so maintained during the entire period of growth of the plants. The results are expressed in the following table:

TABLE 14. — EFFECT OF SOIL MOISTURE ON TRANSPIRATION

Soil Moisture Percentage of Total Capacity	Transpiration Ratio
100	290
80	262
60	239
45	229
35	252

The most economical utilization of water was secured by a medium water supply.

78. Effect of humidity, wind and temperature of the air. — A dry atmosphere and a high temperature increase the transpiration ratio. For this reason crops require a large amount of water in arid regions and in regions of high summer temperatures. A high and constant wind movement also tends to raise the transpiration ratio. In parts of the country requiring irrigation the economical use of water must be considered. Such a region is likely to have much sunshine associated with high temperatures and dry atmosphere.

79. Effect of soil fertility on transpiration. — A soil high in available plant-food material has, in general, the property of producing crops with a small unit expenditure of water. Experiments in Nebraska gave the following results:

TABLE 15. — RELATIVE WATER REQUIREMENTS OF CORN ON DIFFERENT TYPES OF NEBRASKA SOILS

SOIL	DRY WEIGHT OF PLANTS IN GRAMS PER POT	TRANSPIRATION RATIO
Poor	113	549
Medium	184	479
Fertile	270	392

80. Quantity of water required to mature a crop. — A rough estimate of the quantity of water required to bring to maturity a crop of wheat may be calculated as follows: Assuming the yield to be forty bushels or about two tons of dry matter in straw and grain and the transpiration ratio to be 400, the quantity of water actually used by the plants would be 800 tons to the acre, or equivalent to about 7 inches rainfall. In addition to this there would be an equal or larger quantity of water evaporated directly from the

soil. The annual amount of rainfall required for crop-production is brought to a much higher figure by the loss due to run-off and percolation.

81. Capillary movement and plant requirement. — We have seen that there is a capillary movement of water from the more moist to the less moist soil. As water is absorbed by plants, the moisture content is reduced in the soil surrounding the root-hairs by which the moisture is taken up. Immediately a movement begins to establish equilibrium in the water films and during the time the roots continue to absorb moisture, the movement of capillary water goes on. During the blooming period, plants must have very large quantities of water if they are to develop fully and produce large yields of grain. Capillary movement is necessarily slow, especially in heavy loam and clay soils. It is often impossible for the capillary movement to carry moisture fast enough, except for short distances, to supply plants adequately and the crop suffers for want of moisture. In a dry season the capillary capacity of a soil is likely to be of more importance than the rate of capillary movement, as the supply is more easily available. Hence, in time of drought a loam soil in good tilth is better than a sandy soil.

82. Optimum moisture for plant growth. — Plants wilt for want of water at a moisture content somewhat higher than that represented by hygroscopic moisture. They show the pale color characteristic of too much moisture when a soil is saturated. Before either of these well-known signs of distress is shown, the plant may have too much or too little water to allow of its maximum growth. The optimum moisture content lies somewhere within the range of capillary moisture. It is variously stated by different experimenters to lie between 60 and 90 percent of the water capacity of soils. Probably it varies with different soils.

The range is doubtless greater for a soil in good tilth than for one in poor condition, and the wider the range of optimum moisture content the less likely is a crop to suffer from either extreme.

83. The control of soil moisture. — Since there may be too much or too little water in a soil for its most effective crop production, the problem of moisture control is to remove the excess and to conserve the remainder, attempting to maintain the supply within the range of the optimum moisture content. In heavy soils there is likely to be a surplus of water in the spring and in sandy soils a deficit in midsummer. The excessive water content in the spring is also objectionable because it delays plowing, planting, and germination of seed as well as the early growth of crops. The ways in which water leaves soil are by (1) run-off over the surface; (2) percolation; (3) evaporation; (4) absorption by plants. The last of these is to be encouraged, at least when it is economically accomplished. Run-off should generally be prevented. Percolation and evaporation should be controlled within certain limits.

84. Run-off. — Removal of water in this way is objectionable because the rivulets carry with them the fine particles, which are frequently the most valuable part of a soil, and gullies are formed that may interfere with the working of the land. In regions in which the rainfall is large, and particularly where it falls in torrential showers, more than half of the precipitation may escape in this way. The water so removed is, of course, entirely lost so far as its utilization by plants is concerned. The proportion lost by run-off is greater on slopes than on level land, and on compact soil than on sandy soil or on soil in good tilth.

The removal of excess water by means of open ditches is, to some extent, a utilization of run-off to drain land, but it is not so desirable a method as tile drainage. It is better

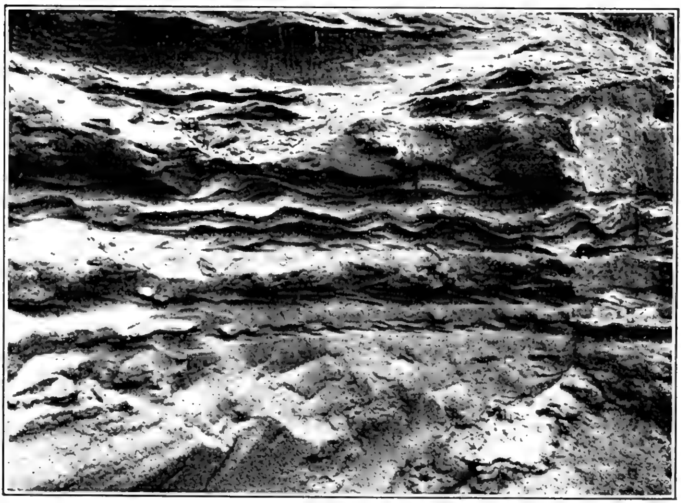


PLATE VIII. FORMS OF EROSION. — Erosion of soil by water in upper figure. Erosion by wind in lower.

to have the moisture pass into the soil and this is encouraged by any of the operations and conditions that favor the maintenance of good tilth. Fall plowing and early spring plowing also serve this end. In arid and semi-arid regions run-off is usually not of any moment. Terracing a hillside is often resorted to as a preventive of run-off, especially in the south Atlantic states where the rainfall is often torrential.

85. Percolation. — Water that enters a soil is either retained by the capillary spaces or eventually percolates into the subsoil. The percolate is lost to crops, except that part which remains in the subsoil and is later raised by capillarity to within reach of roots. The chief consideration is to maintain the soil in good tilth, which gives a large capillary capacity, thus storing within easy reach of the roots a maximum quantity of the descending water. The more rapidly the gravitational water is disposed of the better, because its presence prevents aëration of the soil together with those beneficial processes that good ventilation encourages. One of the most frequent causes of saturation of soil is lack of facility for the water to escape from the lower depths. This difficulty is best relieved by tile drainage.

86. Evaporation. — It has been concluded from experiments conducted at Rothamsted, England, that with an annual rainfall of twenty-eight inches, one-half is lost by percolation. The quantity of water required to produce an average crop in a humid region is about seven inches, which is one-half of the water retained by the soil. The other half is presumably lost by evaporation. A rough estimate of the disposition of rain water in a humid region would therefore be one-half lost by percolation, one-fourth by evaporation and one-fourth used by the growing crop. The ratio of quantity lost by evaporation to quantity used by crop may vary by reason of a number of factors, among which is

the ease with which evaporation may take place. Moisture saved from evaporation is at the immediate disposal of the crop.

87. Mulches for moisture control. — Any material applied to the surface of a soil primarily to prevent loss by evaporation may be designated as a mulch. It may at the same time fulfill other useful functions, like keeping down weeds and maintaining a uniform soil temperature. The mulch ordinarily used for fallow land is produced by stirring the surface soil. Mulches may be formed of straw, leaves, flat stones, cloth, sawdust and various other materials, but the most practical material is soil.

88. The soil mulch. — The soil mulch is made by stirring the surface of the soil with some one of the ordinary tillage implements. For fallow land a disk harrow, straight, or spring tooth harrow may be used. For intertilled crops numerous forms of cultivators are made for the special purpose of going between the rows of plants. For small grain a weeder or spike-tooth harrow, with the teeth slanted backward, is frequently used while the grain is young. This practice has much to recommend it in an arid or semi-arid region.

In making a soil mulch the object is to destroy the capillarity near the surface soil and thus to prevent the movement to the surface of water from the portion of the soil below the mulch. Stirring may accomplish this by breaking up the cohesion of particles to such an extent that moisture cannot pass from one to the other.

89. Frequency of stirring. — Some kinds of soil require more frequent stirring than others. For instance, a sand will maintain a mulch longer than a loam or clay. The latter becomes moist from below and will gradually allow moisture to reach the surface. Rain will also compact a mulch and unless it is soon restored there may be more

moisture lost than was received as rain. While it is not possible to make a definite rule for frequency of stirring a mulch, it may be said that a mulch should never be allowed to remain in a compact condition. However, in arid regions the surface of the soil sometimes becomes completely dry so quickly, even when compact, that capillary connection is destroyed and loss of moisture is prevented.

90. Depth of mulch. — In considering the depth that a mulch should have, several facts should be kept in mind. The deeper the mulch the more effective it will be, but as it must be perfectly dry, roots cannot obtain nourishment in the zone occupied by the mulch. The surface soil, from which plants derive a large part of their material, is frequently only eight to ten inches deep in humid regions and the deeper the mulch the less top soil remains for roots. In arid regions plants obtain food materials from greater depths and mulches may be made deeper, which is fortunate since they need to be deeper in regions where evaporation is greater. Another consideration is the disturbance of roots in the process of cultivation. Here, again, there is less occasion to cultivate shallow in an arid region, as roots are generally found at greater depths in such soils.

A good depth for a mulch in humid regions is about three inches, becoming somewhat less during the last cultivations of corn. In irrigated regions a mulch of ten to twelve inches is frequently used, especially in orchards, in which it is often not necessary to renew the mulch, as the rainfall is usually light.

91. Effectiveness of mulches. — That mulches are effective in conserving moisture and increasing crop yield has lately been called in question by certain writers who claim that corn is not more benefited by tillage than by the removal of weeds without tillage, and by some experimenters who find that fallow land contains as much moisture

when weeds are removed by scraping the surface of the ground as when the soil mulch is maintained. It seems possible that the latter result may occur only in those regions in which conditions are such that a natural mulch is formed by the rapid drying of the surface soil, in which process moisture is removed so quickly that the capillary column is broken and further loss of moisture is stopped. This would confine it to semi-arid and arid regions of high summer temperatures.

The failure of the soil mulch to conserve moisture in corn land has been explained on the supposition that the corn roots ramifying through the upper soil absorb so much water that they cut off the upward movement as effectually as does a mulch. The results of some experiments in semi-arid Montana indicate a high degree of usefulness for the mulch.

TABLE 16. — MOISTURE CONTENT OF MULCHED AND UNMULCHED EASTERN MONTANA SOILS. AVERAGE OF THREE YEARS

DEPTH OF SAMPLE	PERCENT MOISTURE IN SOIL ON OCT 6.	
	Mulched	Unmulched
First foot	16.8	10.8
Second foot	16.4	9.4
Third foot	13.2	9.5
Fourth foot	10.1	8.9
Fifth foot	9.6	8.5
Average	13.2	9.4

The investigator comments on these results as follows: "If the wilting point of this soil is 6 percent, the mulched area contains more than twice as much available moisture. This 3.8 percent of available moisture by which the mulched soil excels the unmulched is equivalent in a five-foot depth to about 250 tons of water, enough to increase the crop by a ton of dry matter."

92. Other devices to prevent evaporation. — Plowing in the early spring or immediately after taking off a crop of small grain is a means of preventing evaporation. In regions

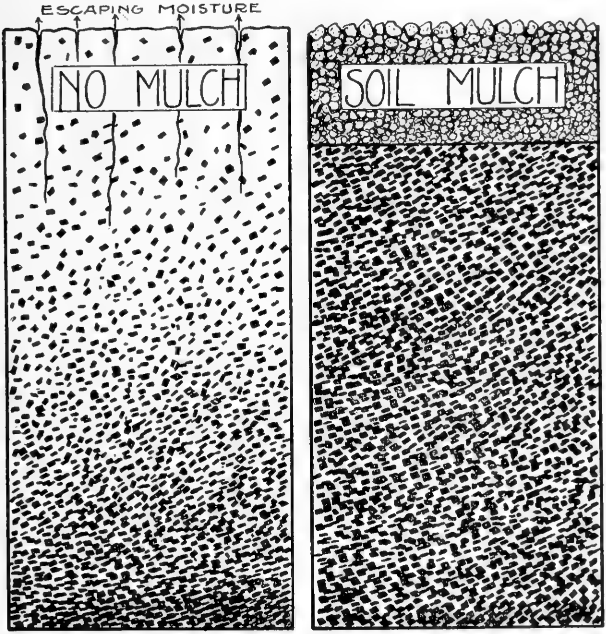


FIG. 14. — The effect of a soil mulch is to break up the capillary spaces within the mulch itself and thus to prevent the upward movement of water through it. Water, therefore, remains in the lower soil instead of evaporating from the surface. This condition is shown in the right-hand column. When no mulch is maintained the soil dries at the surface and then cracks, which allows it to dry more rapidly below.

in which grain crops suffer for moisture in the early spring, it is not uncommon for farmers to harrow the small grain, following the drill rows with a spike-tooth harrow with its teeth turned backwards. This practice is likely to be very beneficial.

Windbreaks are effective in decreasing evaporation by lessening the velocity of the wind. King found that evaporation from a moist soil was twenty-four percent less at a distance of twenty to sixty feet from a black oak grove than it was about three hundred feet distant.

93. Rolling and subsurface packing. — These operations are resorted to in order to bring moisture to the surface or upper layer of soil. Rolling compacts the superficial layer of soil and thus establishes capillary connection with the moist soil below. This may be desirable in order to bring moisture in contact with seeds, but although germination is hastened loss of moisture results.

Subsurface packing is designed to make more compact a naturally loose soil by running wedge-rimmed wheels through it. If the soil is too loose for capillary movement of water to proceed effectively, this operation promotes it. Its use is confined to arid or semi-arid regions.

94. Removal of water by drainage. — Land drainage is any condition, natural or artificial, that enables the surplus water to escape from soils. A soil may be highly productive when drained, but worthless before draining. This is but another illustration of the many factors affecting soil productiveness. Where natural drainage is poor, artificial drainage is generally a profitable investment. It may be accomplished either by surface ditches or by underground drains.

95. Benefits of drainage. — There are many ways in which good drainage benefits soils and crops. The need of drainage may be very evident in the yellow color and poor growth of young plants, or it may be less readily detected, and yet may be sufficiently needed to make it a profitable investment. Good drainage is the first requisite in enabling a soil to reach its maximum productiveness. The principal ways in which drainage benefits the soil and crop are as follows:

1. Enlargement in the supply and movement of soil air.
2. Improvement in tilth.
3. More available water throughout the growing season.
4. Longer growing season.

96. Soil air. — Drainage increases the supply and movement of soil air by allowing the gravitational water to run off and thus to be replaced by air. With each fall of rain there is a movement of air through the soil. The increased air supply is of benefit in the following ways:

1. It furnishes air to roots which require it for the proper performance of their functions.

2. It facilitates the decomposition of organic matter of all kinds, thus disposing of the vegetable matter incorporated with the soil, and permitting the most beneficial kind of decomposition (see §§ 59, 60).

3. It furnishes the conditions necessary for the transformations of nitrogen in the soil which prepare that substance to be used by plants (see §§ 116–168).

97. Soil tilth. — Alternate drying and wetting of soil is one of the processes that causes the formation of granular structure and consequent improvement of tilth. A soil that is constantly saturated or very wet when worked in the spring assumes a compact condition. The larger air space reduces heaving by allowing expansion of freezing water within the soil, and diminishes the tendency to erosion, by allowing water to sink quickly into the soil, instead of running over the surface.

98. Available water during the growing season. — A soil in need of drainage is often in need of moisture in midsummer, because when it does dry out its water-holding capacity is low, on account of its compact condition. Furthermore, plants form shallow roots in a saturated soil, and if the weather becomes dry later in the season, the roots do not then go to the depth necessary to reach the water supply.

It frequently happens, therefore, that plants suffer much from lack of moisture on a soil that has been saturated with water during the early part of the growing season.

99. Length of growing season. — Drainage increases the length of the growing season in two ways: (1) The soil can be worked much earlier than on poorly drained land. (2) The soil becomes warm earlier, because it is easier to heat soil particles than it is to heat water. Then too the evaporating moisture causes a lowering of the soil temperature. Seeds germinate more quickly and uniformly and plants make a more rapid growth on account of the warmer soil.

100. Other results of drainage. — All of these improved conditions unite to produce larger yields of crops and more uniform growth. Drainage eliminates the continually wet or swampy portions of fields that interfere with tillage operations and necessitate working the field in sections. There is, accordingly, an economy in operation. In meadows and pastures the kinds of forage plants that grow on a well-drained soil make better feed than those kinds that grow on wet land.

101. Open ditches. — Excess water is sometimes removed by means of open ditches of size and depth necessary to drain water from the land and carry it to some waterway. Such ditches sometimes merely follow a depression or swale in the land and thus carry off the worst of the excess water, especially that which comes from higher land, or they are sometimes laid out in a more systematic way.

Level fields may be plowed in lands with dead furrows every twelve to twenty feet apart, and with a larger ditch run through lower ground for the dead furrows to empty into. This affords only surface drainage, but is better than nothing. Larger ditches should have grass planted along the sides for several feet from the ditch. Weeds must be mowed and trash, dirt and stones removed at intervals.

Open ditches require much labor to keep them in order, they do not remove the water so thoroughly as do tile drains, and they not only occupy a considerable area but they interfere with the cultivation of much land on account of the space along the ditches required for turning the teams in cultural operations. Only under exceptional conditions may open ditches be profitably used instead of tile drains.

102. Tile drains. — These drains are composed of baked clay or hardened concrete cylinders with open ends, their length being about one foot and their diameter varying from three inches to eight or more. These tiles are laid end to end on the bottom of ditches two to four feet in depth, having a fall sufficient to carry off the water and prevent the tiles from becoming clogged with soil particles. Tile should not be made of clay that contains particles of lime, as the lime when baked is converted into quicklime, which causes the tile to crumble when buried in the soil.

It is not necessary that tile shall be permeable to water, as it is through the openings between the ends of the tile that water enters, and not through the pores. Vitrified tile may well be used, as they are less likely to be injured by freezing than are porous tile, because expansion of absorbed water on freezing causes the latter to disintegrate.

Concrete tile are often used and these may be made on the farm, with forms constructed for the purpose.

Silt and fine sand may enter the tiles through the openings between them, and to guard against this collars are sometimes placed over the joints, but with proper grades this is not necessary. Sometimes tile are hexagonal on the outside, for the purpose of preventing settling of the tile in places, with a consequent stoppage with silt. However, if the bottom of the ditch is carefully made, round tile are not likely to deviate from alignment and they are more easily laid.

103. Arrangement of drains. — In laying out a system of drains certain rules must be regarded. A main drain usually follows a depression in the land, rising with the natural grade, or if that does not give a sufficient rise, becoming shallower as it ascends. Sometimes this will be sufficient to remove the surplus water, but more often lateral drains will be necessary. These are of smaller tile and are usually parallel to each other and from twenty to a hundred feet apart. This arrangement is called the herring bone system. (See Fig. 15.) There may also be submains branching off of the main drain, and laterals running into the submains. This is known as the gridiron system. (See Fig. 15.) Sometimes the laterals are run across the slope, but usually it is better to run them down.

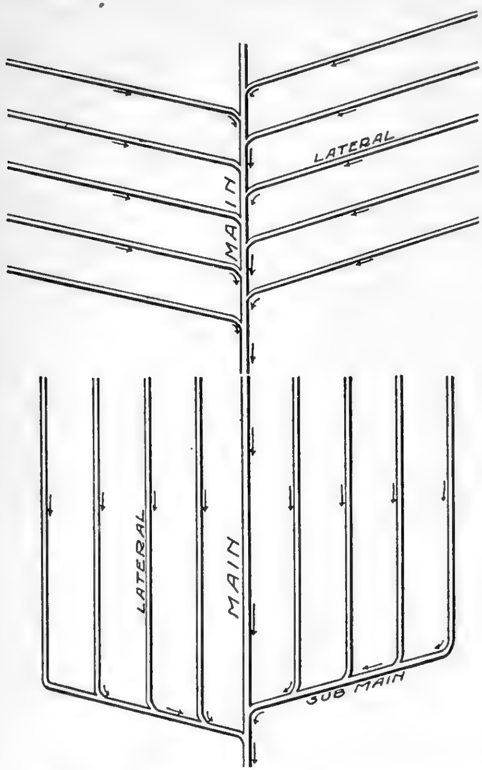


Fig. 15. — The upper drawing illustrates the herring bone system of laying tile drains. The lower represents the gridiron system.

A lateral should not enter a main drain at a right angle,

PLATE IX. DRAINAGE. — The drain outlet is often poorly constructed and easily clogged, as shown in the upper figure. The lower one is well protected.

but an acute angle should be formed between the two streams above the point of contact; otherwise the flow of water will be impeded. For the same reason two laterals should not enter a main drain opposite to each other.

It is desirable to have as few main drain outlets as possible, for the outlet is likely to be the weakest point in a drainage system. If it becomes clogged, the entire system is put out of action. It is more likely to be injured by freezing than is the underground tile, and unless well protected it affords an opening into which small animals may crawl and clog the system.

The quantity of water removed by tiles of various sizes, and laid at certain distances and grades as well as other operations that cannot be treated here, may be ascertained from the books that deal exclusively with the subject of land drainage.

104. Digging ditches and laying tile. — The depth of ditches for tile drainage varies from two to four feet. Three feet is the usual depth. The closer together the laterals, the shallower the drains may be laid. A compact soil, through which water moves very slowly, will require the use of shallow drains. A lighter soil underlaid by hardpan will also require shallow drains. The shallower the drains in any soil, the closer together they must be laid, the customary range being from twenty to a hundred or more feet. Surplus water enters the drains from the soil immediately surrounding them. As the larger pore spaces become partly empty, water enters them from surrounding soil, and in this way drainage gradually extends. The soil midway between the drains is the last to lose its surplus water, and the water table is always higher between drains than over them.

The distance between drains must be small enough to allow the water table to descend promptly to a point where

it will not interfere with root growth. The more permeable the soil and the deeper the drains, the further apart they may

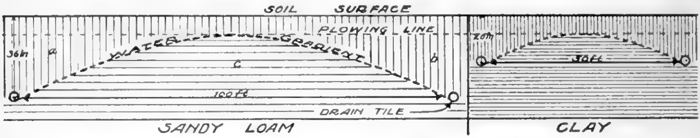


FIG. 16. — Cross sections of two soils, a sandy loam and a clay, both of which have drain tiles laid at right angles to the sections. Owing to the more rapid movement of water through the sandy loam, the tiles are laid twice as far apart as they are in the clay. They are also deeper in the former soil. The water gradient is steeper in the clay. The tiles should be sufficiently close together to keep the water table below the plowing line.

be placed. The position of the water level between drains is shown in Fig. 16.

Ditches may be dug or partly dug by means of spades, ditching plows or traction ditchers. The last named, while

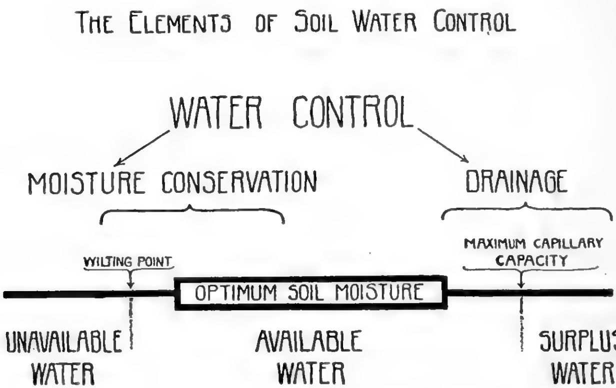


FIG. 17. — Diagrammatic explanation of water control in a humid region. On the one hand we have drainage reducing the surplus water to the maximum capillary water capacity or below and thus bringing it within the range of available water. On the other we have moisture conservation by means of which the moisture is kept above the content of unavailable water or the wilting point. Somewhere within the limits of available water lies the optimum moisture content for plant growth.

expensive in first cost, is economical in operation in many soils. After the ditch has been opened to its full depth, it is necessary to go over the entire bottom to remove loose dirt and to give it the necessary grade. This must be done by hand. Either a ditching spade or a drain scoop is the best implement to use. A fall of at least four inches in a hundred feet is necessary under most conditions, but in clay soils less fall is permissible, as there is less danger of silt entering the drains.

QUESTIONS

1. Name the three forms in which water is present in soils.
2. Explain what is meant by hygroscopic water. Capillary water. Gravitational water.
3. On what does the content of hygroscopic water depend ?
4. Name six conditions that tend to increase the capillary water capacity of soil.
5. Explain the relation of soil texture to the movement of capillary water.
6. How does soil texture affect the rate of movement of capillary water ?
7. What are the conditions that affect the rate of flow of gravitational water ?
8. Explain what is meant by the water table.
9. Describe three ways in which water contributes directly to plant growth.
10. What is the transpiration ratio ?
11. Name three factors that influence it.
12. Calculate the number of inches of rainfall transpired by a three-ton crop having a transpiration ratio of 250.
13. Name four ways in which water leaves soil.
14. What is the principle of the soil mulch ?
15. State four ways in which drainage benefits soils.

LABORATORY EXERCISES

Exercise I. — Determination of the percentage of water in a soil.

Materials. — Samples of moist soil, torsion balance, evaporating dishes, air oven and flame, desiccator. See Plate IX.

Procedure. — Carefully obtain the weight of an evaporating dish on the balance. Then weigh into the dish 50 grams of the soil to be tested. Air dry sample in laboratory and then place it in air oven at 100° C. for two hours. Cool in desiccator and weigh. The loss in weight is water. Calculate the percentage of moisture based on absolutely dry soil.

Make this determination in duplicate and on a number of soils. Calculate the amount of water in an acre foot of the various soils, considering them to weigh 3,500,000 pounds per acre foot. Note relation of soil moisture content to bare and cropped soil, kind of crop, stage of growth and previous rainfall.

Exercise II. — Capillary movement in different soils.

Materials. — Dry samples of pulverized sandy loam, silt and clay, three long glass tubes 2 inches in diameter, pans for water and cheesecloth. See Plate IX.

Procedure. — Neatly cover the ends of the three long glass cylinders by tying over them two thicknesses of cheesecloth. Fill cylinders with the respective soils to be studied. Be sure that the compaction is uniform. Now set the ends of the cylinders in water one inch deep and observe the height of capillary movement at the following periods after starting: 1 hour, 2 hours, 12 hours, 1 day, 2 days, 3 days, 4 days, etc. Continue experiment as long as practicable. Tabulate data and draw curves. Explain the practical importance of the results obtained.

Exercise III. — Rate of percolation of water through soils.

Materials. — Dry, well-pulverized sand and clay loam, two lamp chimneys, cheesecloth, torsion balance. See Exercise V, Chapter V.

Procedure. — Prepare two lamp chimneys by neatly tying two thicknesses of cheesecloth over their bottoms. Place in one a definite and known amount of sand. In the other place the same weight of clay loam. Give each a uniform compaction. Now weigh each chimney with its content of soil.

Place the chimneys in such a position as to allow free drainage and add the same amount of water to each, keeping the head of water constant in each chimney. Observe the rate of the downward movement of water through the two soils. When percolation has begun, measure percolate for 15 minutes and express rate in cubic centimeters per hour.

Explain the reasons for the results obtained and the practical importance thereof.

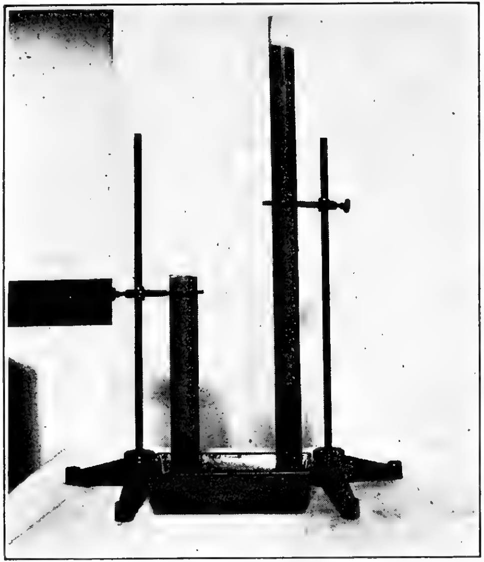
 

Plate X. Apparatus for Moisture Measurement. — Figure on right shows apparatus used in determination of moisture in soils. Figure on left shows apparatus used in demonstration of the capillary rise of water in soils.

Exercise IV. — Water-holding capacity of soils.

Materials. — Same as in Exercise III.

Procedure. — When Exercise III is complete, cover chimneys and allow all the free water to drain away. Then weigh the chimneys and wet soil. The increased weight is water retained. Calculate the percentage of water retained by each soil based on the weight of the original sample.

Write out a full description of the experiment and the points of importance that it shows.

Exercise V. — Moisture conservation by means of a soil mulch.

Materials. — Three tumblers, one of which should be one inch shorter than the other two, moist soil, dry clay loam and dry sand, torsion balance.

Procedure. — Fill the short tumbler level full with a well-mixed moist soil. This is to serve as the unmulched treatment. Place

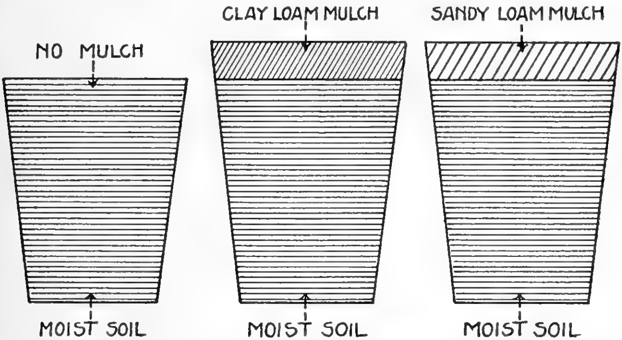


Fig. 18. — Tumblers filled with equal quantities of a moist soil and prepared for a demonstration of the effectiveness of mulches in the conservation of moisture. Losses of moisture by evaporation are measured by weighing the tumblers.

exactly the same amount of moist soil in each of the other tumblers as is used in the shorter one, compacting to within one inch of the top. On the surface of one place one inch of dry clay loam and on the other one inch of dry sand. Weigh the tumblers now fully prepared.

Set tumblers in a place of uniform temperature and weigh daily for a week. The loss of weight each day is moisture. Tabulate data and draw curves.

Explain the significance of the results obtained.

Exercise VI. — Loss of water by transpiration.

Materials. — Glazed gallon butter jar, oats seed, paraffined paper, thistle tube, coarse sand and heavy balance.

Procedure. — Fill a glazed jar with rich soil, first adjusting coarse sand and thistle tube as shown in Fig. 19. Moisten soil with water, but not too wet, and plant with oat seed. When seedlings are one week old, thin to suitable number. Then cover surface of soil with paraffined paper, allowing plants to protrude through small holes cut for that purpose. Paraffine the paper to side of jar so that all losses of moisture by evaporation may be prevented. Bring soil up to optimum water content and weigh. You are now ready to record losses by transpiration.

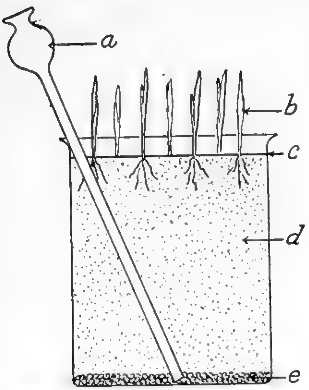


Fig. 19. — Glazed jar equipped for observation of transpiration of water from plants. (*a*) thistle tube for watering, (*b*) plants, (*c*) paraffined paper to prevent evaporation from the soil surface, (*d*) soil, (*e*) gravel.

Weigh jar each week, replacing water lost through the thistle tube. Record data and draw curves. By changing the jar from sunshine to shade, warm temperature to cold, high humidity to low, etc., the factors influencing transpiration may be studied.

Jars with different crops, different soil or the same soil with different fertilizers or different water treatments may be utilized if so desired.

Exercise VII. — Review problems. Chapters IV and VI.

1. A soil weighs 100 lbs. per cubic foot when dry. The weight of a cubic foot of water is 62.5 lbs. Calculate its apparent specific gravity and weight per acre foot. *Ans.* 1.6 and 4,356,000 lbs.

2. This soil has an absolute specific gravity of 2.7. Calculate its pore space.

$$\% \text{ pore space} = 100 - \left[\frac{\text{ap. sp. gr.}}{\text{abs. sp. gr.}} \times \frac{100}{1}\right] \qquad \textit{Ans. } 40.7^{+}\ \%.$$

3. This soil contains 10 pounds of water a cubic foot. Calculate percentage of water based on absolutely dry soil. On wet soil. *Ans.* 10 % and 9.09 %.

4. By the following formula, calculate the air space present.

% air space = % pore space − (% water × ap. sp. gr.) *Ans.* 24.7 %.

5. The wilting point in this soil is 4 percent. What is the percentage of available water? Weight of available water per cubic foot? Per acre foot? *Ans.* 6 %, 6 lbs. and 261,360 lbs.

Exercise VIII. — Tile drainage.

If possible, have the class install a short drainage system. They should dig at least part of the ditch, grade the bottom, lay the tile and build the outlet. The explanation of every point involved as the work proceeds will give such an exercise great practical value. It will also make the classroom work much more effective.

If drainage operations are being conducted in the near vicinity, the class should by all means be taken to inspect them. The general plan of the work, as well as the more detailed phases, should be explained by the teacher. Materials and illustrations may also be obtained for later discussion and study in the classroom. If ditching machinery is being utilized, it also should be given considerable study.

Early in the spring, while the soil is still wet, a field trip might well be taken. The need of drainage, the movement of water through soil, the effectiveness of drainage, the entrance of water into a drainage system, the movement of water through tile, good and poor outlets and the drainage of roads could be studied with profit.

CHAPTER VII

PLANT-FOOD MATERIALS IN SOILS

Plants secure their mineral food materials exclusively from the soil. In a state of nature plants at death fall on the surface of the ground and as decay proceeds, their ash constituents return to the soil. The loss of mineral matter, under these conditions, is due almost entirely to its solution and removal in drainage water, or to erosion. Under ordinary farm practice the procedure is different. The aboveground portions of plants are removed wholly, or in part, from the land and the loss of easily soluble mineral matter is thus greatly increased. The soil supply of those particular elements required for the growth of crops is a matter of great importance, for it is upon this that man must depend for his sustenance, and although he may supplement these elements in the soil by the use of manures, the cost of food is thereby materially increased.

105. Variations in content of plant nutrients in different soils. — There are wide differences in the quantities of plant-food materials in soils from different localities, although the localities may be near together. This is illustrated by the following statement of the analyses of soils from different parts of the country, the number of pounds of each ingredient being based on the weight of 2,000,000 pounds of soil, which is about the weight of the furrow slice of an acre of land.

TABLE 17. — COMPOSITION OF SOME ARABLE SOILS BASED ON ULTIMATE ANALYSES

Location	Pounds in 2,000,000 Lbs. of Soil				Percentage Composition			
	Nitrogen	Phosphoric Acid	Potash	Lime	Nitrogen	Phosphoric Acid	Potash	Lime
New York	2,520	1,680	40,200	6,600	0.126	0.084	2.010	0.330
New York	2,860	1,620	33,400	4,600	0.143	0.081	1.670	0.230
New York	2,800	3,280	17,200	68,400	0.140	0.164	0.860	3.420
New York	4,000	3,920	39,200	5,400	0.200	0.196	1.960	0.270
Ohio [1]	1,260	966	43,975	11,303	0.063	0.043	2.198	0.565
Ohio [1]	3,844	14,008	67,285	78,772	0.192	0.700	3.364	3.938
Ohio [1]	186	3,106	37,214	15,478	0.009	0.155	1.860	0.773
Ohio [1]	2,974	1,580	37,070	4,480	0.148	0.079	1.853	0.224
Illinois [2]	6,480	4,145	42,493	28,644	0.324	0.207	2.124	1.432
Illinois [3]	6,020	3,710	39,165	104,636	0.301	0.185	1.958	5.232

The soils whose analyses are stated in the table given above are all from arable land and while they represent wide differences in some of their constituents none of them is so deficient in any plant nutrient as to prevent it from producing crops. Comparing the quantities of the constituents of these soils, we find that in the Illinois soils the lime varies from 28,644 pounds to 104,636 pounds in 2,000,000 pounds of soil. In Ohio the same constituent ranges from 4480 to 78,772 pounds with nearly as low a minimum in New York. The nitrogen in Ohio rises from a minimum of 186 pounds to a maximum of 3844 pounds while the maximum for Illinois is 6480 pounds. The greatest range of phosphoric acid is from 966 pounds to 14,008 pounds, both of which soils occur in the same state.

Another fact brought out by this table is that a soil may be rich in one ingredient and poor in another, also that soils lying near together may differ more in composition than do soils that are widely separated.

[1] Ohio Experiment Station Bul. 261. [2] Illinois Soil Report No. 2.
[3] Illinois Soil Report No. 10.

106. The total supply of plant-food materials. — The statement of analyses in Table 17 shows the quantities of plant nutrients in 2,000,000 pounds, which represents the weight of an acre of soil to a depth of only six to eight inches. There is below this a considerable volume of soil through which roots ramify, and from which some nutriment is drawn. The roots of ordinary crops extend to a depth of three or four feet into the soil, depending on different conditions of soil and climate. In semi-arid and arid regions roots extend deeper than they do in humid regions, and in well-drained soils they penetrate deeper than they do in poorly drained ones. It is, however, from the furrow slice that plants derive most of their nourishment.

Subsoils sometimes contain more and sometimes less plant-food materials than do the surface soils. Nitrogen is almost always present in greater quantity in the surface soil, because it is a constituent of material that has been plowed into the furrow slice. Table 18 contains a statement of the analyses, expressed in percentage composition, of two soils to a depth of four feet, each foot of which was analyzed separately.

TABLE 18. — ULTIMATE ANALYSES OF TWO SOILS TO A DEPTH OF FOUR FEET, EXPRESSED IN PERCENTAGE COMPOSITION

	DUNKIRK CLAY LOAM				VOLUSIA SILT LOAM			
	1st ft.	2nd ft.	3rd ft.	4th ft.	1st ft.	2nd ft.	3rd ft.	4th ft.
Nitrogen	.126	.067	.064	.064	.143	.052	.059	.050
Phosphoric acid	.084	.066	.103	.125	.081	.039	.018	.071
Lime	.330	.270	.520	1.780	.230	.160	.260	.360
Magnesia	.160	.150	.150	.320	.560	.390	.290	.400
Potash	2.010	2.480	2.550	2.630	1.670	1.790	2.000	2.140

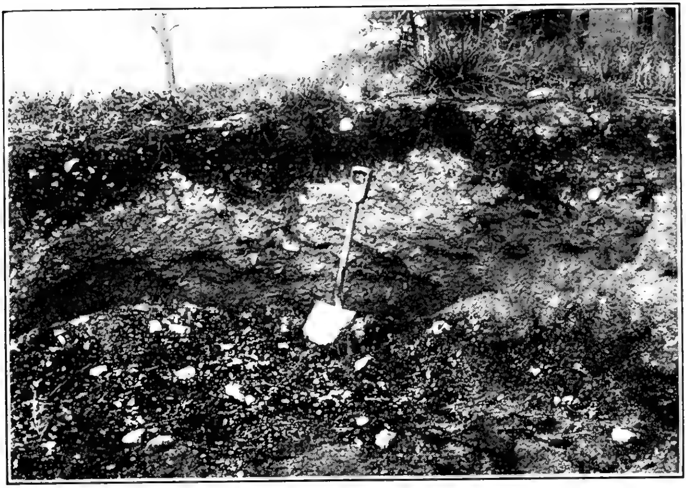


PLATE XI. SURFACE SOIL AND SUBSOIL. — Note the difference between the top soil and the subsoil in the upper figure; also the abundant growth of plant roots in the top soil as compared with the subsoil in the lower figure.

These analyses show in some cases more, and in others less, of the various constituents below the surface foot, with the exception of nitrogen, which is always less in the subsoil. The fact that the greater part of the roots of most plants is in the surface soil makes the draft greater on that layer, but the total volume to a depth of four feet, or even more, may be considered to be the feeding ground of crops.

107. Upward movement of plant-food materials. — There is another way in which the soil to a considerable depth may contribute to the nourishment of crops. This is by furnishing plant-food materials that are carried upward by ascending currents of moisture, or that are absorbed by roots from the lower depths and deposited near the surface when the plants die. To what extent the upward movement due to moisture is operative is something of a question; in humid regions probably very slightly, in semi-arid and arid regions it is doubtless of considerable moment, as indicated by the existence of alkali crusts.

108. Plant nutrients compose a small part of the soil. — Another point brought out by Table 17 is the very small proportion of the soil that is represented by plant-food materials. For instance, the sum of all of the nitrogen, phosphoric acid, lime, magnesia and potash is not much more than two percent of the total weight of the soil, and it would be easy to find analyses that would show much less. Some of the very important substances are present only in tenths or even hundredths of a percent. The great bulk of the soil contributes nothing to plant growth other than to furnish mechanical support and to store air and water for the use of roots.

109. Relation of composition to productiveness. — The productiveness of a soil is not necessarily directly proportional to the quantity of plant-food materials that it con-

tains. This is because there are so many conditions, to which soils are subject, that interfere with the ability of plants to obtain the nutrients or that, in other ways, interfere with plant growth. It is, however, possible for the quantity of some substance required by plants to be so small that it is not sufficient to furnish enough nutriment for profitable crop production. Probably all of the soils, whose

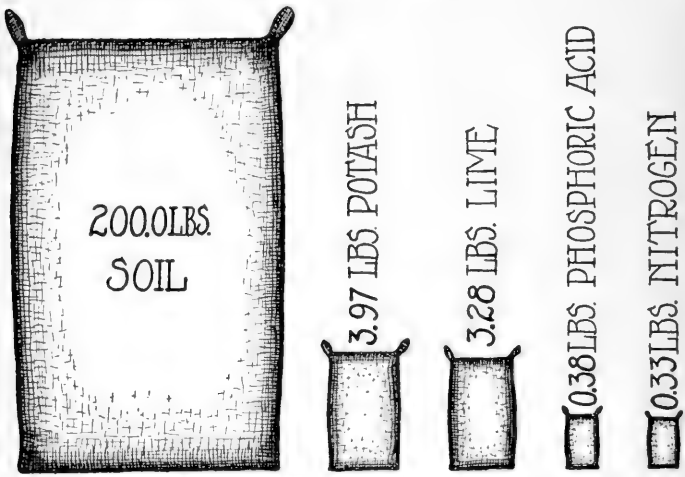


Fig. 20. — Relative quantities of potash, lime, phosphoric acid and nitrogen in a sack containing 200 pounds of dry soil, when the percentages present are respectively 1.98, 1.64, 0.19 and 0.165.

analysis is stated in Table 17, would be benefited by the application of some fertilizers, with the possible exception of the rich prairie soils. This is not because there is not actually enough plant-food material in the soil, but because it is not in a form that is available to plants.

110. Available and unavailable plant-food materials. — The available plant-food materials in soils consist of those portions of the total supply that plants are able to secure in their growth. We have seen that it is necessary for all

substances to be in solution in order that they shall be absorbed by plants. Soil is not readily soluble. The natural insolubility of soil is modified by various conditions of the soil itself and by the plants that grow on it. The rate of availability of plant nutrients is, therefore, not a constant quantity for any soil. A soil in good tilth will produce much better crops than a soil in poor tilth, which means that the rate of availability of its plant nutrients changes with the physical condition of the soil.

The available plant-food materials are not necessarily proportional to the quantities of plant-food materials in a soil. One piece of land may contain more plant nutrients than another and yet be less productive. It has been shown that the addition of four or five volumes of quartz sand to one volume of a heavy, but highly productive, black clay soil greatly increased the productiveness, although the consequent dilution of plant-food content reduced the potash to 0.12 percent and the phosphoric acid to 0.03 percent. The mechanical condition of the soil was better after applying the sand.

111. Conditions that influence availability. — It is apparent that the immediate availability of the plant-food materials in a soil is not so much a matter of their total quantity, as of favorable conditions for the decomposition of both the organic and the inorganic matter in the soil, and for the growth of plants. For this reason good tilth, good drainage, warmth, absence of acidity and the kind and vigor of the plants are factors that influence availability. When any one or more of these conditions is unfavorable, the availability of the plant nutrients may be decreased.

While all of these conditions influence the availability of the plant-food materials, it still remains true that, other things being equal, the greater the total supply of each of these constituents of a soil, the greater will be the total

quantity of available plant nutrients, and the greater the productiveness of the soil is likely to be. Hence, it is desirable to conserve the supplies of these substances and to augment them, if possible, by their judicious application in the form of farm manures and other fertilizing materials, and especially to maintain the store of organic matter.

112. Water-soluble matter in soil. — Although soil is very slightly soluble in water, an extract of soil made with water contains all of the substances required by plants. The solution obtained by extracting a soil with water is probably not identical in composition or concentration with the solution presented to the root-hairs of plants for their nourishment, because the plant by the excretion of carbon dioxide, and possibly in other ways, aids in dissolving plant nutrients. It is probably true, however, that the solution obtained by water is the nearest approximation that we have to the solution presented to roots and is, for that reason, deserving of attention.

113. Relation of water-soluble matter to productiveness. — It might be expected that there would be a direct relation between the productive capacity of a soil and the quantities of plant nutrients in its water extract, and that this relation would hold between different soils. This would imply that, as between two or more soils, the plant-food materials dissolved by water would, in general, be proportional to the quantities of the readily available constituents in the soil. It has been demonstrated that such relations do obtain between certain soils, but it has not been proven that this is invariably the case. Indeed it is probable that soils which differ little in their productivity would not, in every instance, show such a direct proportional relationship. Experiments with four good and four poor soils showed the following averages for their crop yields and water extracts.

TABLE 19. — AVERAGE YIELDS AND COMPOSITION OF WATER EXTRACTS OF FOUR GOOD AND FOUR POOR SOILS

CROP YIELDS PER ACRE	POOR SOILS	GOOD SOILS
Corn, bushels	33.6	64.3
Potatoes, bushels	78.6	213.2
Water soluble salts in pounds per acre of surface four feet		
Nitrogen	30	82
Phosphoric acid	109	192
Potash	219	319
Lime	553	1422
Magnesia	293	576

A somewhat similar result was obtained with two soils contained in large tanks from which drainage water was collected, and that have been under experiment for a number of years. Each tank holds about three and one-half tons of soil. In 1915 tanks filled with soils of different types were planted to corn. The yields of grain and stalks combined are given in Table 20 and also the number of pounds to the acre of plant nutrients in drainage water collected during seven months from the same soil types kept bare of vegetation. As only a trace of phosphoric acid was found in the drainage that ingredient is not included in the table.

TABLE 20. — YIELDS OF CROP AND PLANT-FOOD MATERIAL IN DRAINAGE WATER FROM TWO SOIL TYPES

	SOIL TYPE	
	Dunkirk Clay Loam	Volusia Silt Loam
Yield of corn silage (tons per acre)	13.4	7.8
Substances in drainage water (lbs. per acre)		
Nitrogen	72	59
Lime	438	360
Magnesia	81	57
Potash	100	52

In this case, as in that of the four soils, previously cited, there is a correlation between the productiveness of the soils and the composition of the water extract.

114. Chemical analysis of soil. — There have been many methods devised for the chemical analysis of soil. The important difference between these is in the solvent used to bring the soil into solution. Most solvents dissolve only a part of the soil, in which case the result of the analysis does not show the entire amount of all the constituents, and does not, therefore, show the total quantity of the plant-food materials in the soils. The figures given in Table 17 are obtained from a complete solution of the soils analyzed and hence show their ultimate composition.

The advantage of an analysis of this kind is that one can judge of the lasting qualities of the soil, and if any particular constituent is present in very minute quantity that fact is disclosed, and measures can be taken to augment the supply, but nothing, however, as to immediate productiveness can be learned. A collection of rocks may yield to this analysis as much phosphoric acid, potash, lime, or other nutrient, as a rich soil. Such an analysis is useful only to ascertain the ultimate limitations of a soil, or its possible deficiency in any essential constituent.

Various solvents have been used with the intention of finding the quantities of food materials that plants may be expected to obtain in a reasonable length of time, or in other words to determine the available plant-food materials. These methods fail because availability, as we have just seen, depends on the conditions to which a soil is subjected in the field, and as these naturally vary from time to time it is impossible to find any one solvent that will measure such a variable quantity as availability.

Chemical analyses of soil are useful in connection with investigations of questions relating to soils but it is not

always possible, as the result of a chemical analysis, to estimate the degree of productiveness of a soil, or to say that it should have a certain kind of fertilizer treatment, or that it is adapted to certain crops.

115. Absorptive properties of soils. — If a solution of certain substances required by plants be poured on soil they will not leach through the soil unaltered, but part will be held by the soil. On the other hand, the drainage water may contain an increased quantity of some other substance in place of the one added in solution. As an example of this we may take the following case. An application of 200 pounds to the acre of a potash fertilizer was made annually for five years to soil contained in one of the large tanks previously referred to. The composition of the drainage water from the tank so treated, and of the drainage water from an untreated soil is shown in the following table:

TABLE 21. — ANNUAL AVERAGE POUNDS TO THE ACRE OF LIME, MAGNESIA AND POTASH IN DRAINAGE FROM SOIL TREATED WITH POTASH FERTILIZER AND FROM UNTREATED SOIL

SOIL TREATMENT	CONSTITUENTS IN DRAINAGE WATER		
	Lime	Magnesia	Potash
Potash fertilizer	298	81	53
No fertilizer	248	56	55

In this case the effect of the application of the potash fertilizer was to increase the quantities of lime and magnesia in the drainage water, but not the quantity of potash.

116. Selective absorption. — Some substances are retained by soils only in small part. Among these are nitrates, which, as we shall see later, are very important forms of nitrogen, and sulfates, which are also required by plants.

When sulfate was added annually to soil in one of the tanks already mentioned, for a period of five years, as much as two-thirds of the quantity applied was removed in the drainage water, in addition to what would have been removed if the soil had received no sulfate. The potash previously mentioned as having been applied to this soil, and the sulfate here spoken of were one substance called sulfate of potash. The latter was held by the soil and the sulfate largely leached through. It is evident that the substance was decomposed in part or in whole.

It is thus apparent that there are certain soluble fertilizers that may be applied to soils without much danger of loss by leaching and other fertilizers that are likely to be partly carried out of the soil in this way.

117. The availability of absorbed fertilizers. — When a soluble fertilizer is absorbed by a soil, a part of it, at least, is held in a condition in which it is more readily available to plants than is the large mass of plant-food material originally in the soil. Thus there may be in a soil several thousand pounds to an acre of nitrogen, phosphoric acid or potash in the three or four feet through which roots ramify, and yet the yield of crops on this soil may be materially increased by the application of less than a hundred pounds of one or more of these substances.

The ability of soil to hold fertilizers in a readily available form is strikingly illustrated by an experiment at the Rothamsted Experiment Station in which soil from plats that had been treated with certain fertilizers for many years was thoroughly extracted with water and the extracts analyzed. Complete analyses of the soil from the several plats were also made. The yields of crops on these plats had been recorded for many years and the annual average of these, together with the analytical data, is given in the accompanying table:

TABLE 22. — YIELDS OF CROPS AND COMPOSITION OF SOIL AND WATER EXTRACT OF SOIL

SOIL TREATMENT	YIELD PER ACRE	COMPLETE ANALYSIS PERCENTAGES		WATER EXTRACT PARTS PER MILLION	
	Pounds	Phosphoric acid	Potash	Phosphoric acid	Potash
Unmanured	1,276	0.099	0.183	0.525	3.40
Nitrogen and phosphoric acid	3,972	0.173	0.248	3.900	3.88
Nitrogen and potash . .	2,985	0.102	0.257	0.808	30.33
Complete fertilizer . . .	5,087	0.182	0.326	4.025	24.03
Farm manure	6,184	0.176	0.167	4.463	26.45

It may be observed that the water extract of the soil from the plats treated with any fertilizer ingredient was much richer in that constituent than were the plats not so treated, while the total quantities found in the soil were not proportionately increased.

118. Other forms of available plant-food materials in soil. — The natural weathering of soil that goes on continually makes soluble a part of the originally insoluble mineral matter and this is absorbed just as are the fertilizer salts. When land is cropped each year, this soluble matter is used by plants about as quickly as it is formed, but when land is bare fallowed the dissolved matter is largely absorbed, and thus a bare fallow increases the quantity of available nutrients for the following crop.

Another, and very important supply of available plant nutrients, is that combined with the organic matter in soils. When organic matter is incorporated with soil, decomposition begins, acids are formed and these unite with mineral matter previously in a difficultly soluble condition. The result is a compound, partly organic and partly inorganic. These compounds decay still further until all the organic matter passes off as we have already seen (§ 50), and the

inorganic matter that remains is either used directly by plants or is absorbed in the same way as the soluble fertilizers.

In an experiment several organic substances were mixed with soil, the quantities of phosphoric acid and potash combined with organic matter being determined before mixing and after standing for a year or more. The results of some of these experiments are given in the following table:

Table 23. — Combinations of Phosphoric Acid and Potash with Organic Matter Produced by Mixing Organic Matter with Soil

	Phosphoric Acid Grams	Potash Grams
Experiment with cow manure and soil		
In original manure and soil	1.17	1.06
In mixture after standing	1.62	1.27
Gain in organic form	0.45	0.21
Experiment with green clover		
In original soil and clover	3.21	5.26
In mixture after standing	3.74	4.93
Gain in organic form	0.53 loss	0.33
Experiment with meat scrap		
In original soil and meat scrap	1.07	0.25
In mixture after standing	1.18	0.36
Gain in organic form	0.11	0.11

When the organic compounds thus formed undergo further decay the inorganic plant-food materials become available.

119. Loss of plant-food material in drainage water. — The drainage water from cultivated fields in humid regions, and to a less extent in semi-arid and arid regions, except where irrigation is practiced, carries off very considerable quantities of plant-food material. When it is considered that soil is constantly subjected to leaching by rainwater passing through it, that this amounts to many tons of water in the course of a year on every acre of land, and that a water extract of soil always contains some of each of the substances

required for plant growth, it is not hard to realize that there must result a constant and significant loss of fertility. The plant-food materials lost in largest quantity are lime, magnesia, potash, nitrogen and sulfur. Phosphoric acid is not removed in large quantity from any soil and appears only in traces in the drainage water of most soils.

120. Quantities of plant-food materials in drainage. — The quantities of plant-food materials that are removed from soil in the course of a year will depend on a variety of conditions and, to some extent, these and the total losses that may be expected are indicated by the following table, which is based on the annual average loss for a period of five years from a Dunkirk clay loam soil contained in tanks four feet deep and four feet two inches square.

TABLE 24. — NUMBER OF POUNDS OF PLANT-FOOD MATERIALS REMOVED IN DRAINAGE WATER FROM ONE ACRE OF LAND

Tank No.	Crop	Fertilizer	Lime	Magnesia	Potash	Nitrogen	Sulfur
3	Rotation	No fertilizer	281	50	64	7	32
4	No vegetation	No fertilizer	519	99	88	102	45
11	Rotation	Sulfate of Potash	298	81	53	5	56

121. Effect of crop growth on loss of plant nutrients in drainage. — It will be seen that the loss of lime is very large, amounting to several hundred pounds to the acre. The soil with no vegetation has suffered much more in this respect than has the soil that was planted. The soil that was fertilized with sulfate of potash lost somewhat more lime than did the unfertilized soil. The loss of magnesia followed the same course as did the lime. More potash was lost from the unplanted soil than from the cropped, but the use of a potash fertilizer did not increase the removal of potash.

In the case of nitrogen, the effect of not cropping the soil

is astonishing. The loss from the cropped soil is moderate, but from the unplanted soil it is excessive. The loss of sulfur is decreased by cropping, and much increased by fertilizing with sulfate of potash.

The loss of lime and nitrogen in the uncropped soil as compared with the one that was cropped is greater than the quantity that would have been removed by ordinary crops. Consequently there is an actual saving of these plant-food materials when crops are produced.

122. Effect of fertilizers on loss of plant-food materials in drainage. — We have seen that the effect of sulfate of potash was to increase the loss of lime, magnesia and sulfur. In general, the result of fertilizer applications is similar to that shown above. This is borne out by experiments conducted at the Rothamsted Experimental Station in which drainage was collected from plats treated with different fertilizers. The total flow of drainage water from these plats was not measured, but the composition of the water indicates the effect of the fertilizers.

TABLE 25. — COMPOSITION OF DRAINAGE WATER FROM WHEAT PLATS, ROTHAMSTED EXPERIMENT STATION

PLAT No.	MANURES APPLIED, RATE PER ACRE	PARTS PER MILLION			
		Lime	Magnesia	Potash	Nitrogen
2	Farm manure, 14 tons	147.4	4.9	5.4	16.3
3 and 4	No manure	98.1	5.1	1.7	4.0
5	Minerals only	124.3	6.4	5.4	5.2
6	Minerals + 200 lbs. ammonium salts	143.9	7.9	4.4	8.7
8	Minerals + 600 lbs. ammonium salts	197.3	8.9	2.7	17.2
9	Minerals + 550 lbs. nitrate of soda	118.1	5.9	4.1	18.6
13	Ammonium salts + superphosphate + sulfate of potash	201.4	9.3	3.3	17.6

Without going over this table in detail, it may be noticed that the effect of both farm manure and commercial fertilizers is to increase the percentage of plant-food materials in the drainage water.

123. Drainage water from different soils. — The composition of the drainage water varies with different soils. Table 20 in which the composition of the drainage water from Dunkirk clay loam and Volusia silt loam is given, is an illustration of the very considerable differences that may occur in this respect. The more productive soil has lost the greater quantity of plant-food material. The rates of loss, however, are not proportional to the amounts of plant nutrients that the soils contain. The Dunkirk soil contains less nitrogen than the Volusia, but has lost more in the drainage water.

124. Absorption of food materials by plants. — It is only when substances are in solution that they may be absorbed by agricultural plants. This means that the soil from which plants draw their nourishment must contain water. Plants absorb both water and nutrient salts through their roots, more especially through the root-hairs, as these have very delicate walls through which solutions may readily pass. The movements of water and of salts through the walls of the root-hairs are independent of each other. When the weather is very hot and dry, a larger proportion of water to salts will pass into the roots than when the weather is cool and moist.

125. How plants absorb nutrients. — When a solution of plant nutrients is brought in contact with roots, there is a tendency for the solution in the inside of the root and that on the outside to become of the same strength for each particular substance in the solution. Thus, if there is much available nitrogen in the solution, it will be absorbed in greater quantity than if there were very little. Then, when the nitrogen in the plant juice is utilized by the plant to

form tissue, it is removed from the juice and more nitrogen is absorbed to reëstablish equilibrium.

The substances that are used by plants in large amounts are absorbed in greater quantity than those that are not required in making tissue, or in other ways removed from solution in the plant juices. The unused substances that remain in the plant juices prevent, by their presence, the further absorption of those particular substances from the soil water. It is important that substances like nitrogen, phosphoric acid, potash and lime shall be present in abundant quantities in the solution from which crops draw their nourishment.

126. How roots aid in solution of soil. — In addition to their function in the absorption of plant nutrients, there can be no doubt that roots aid in the solution of these nutrients from the soil. One way is by the excretion of carbon dioxide, which when dissolved in water is an excellent solvent for such substances as lime, potash and even phosphoric acid when present in certain forms. The following table shows the percentage of carbon dioxide in air drawn from the bottom of the large soil tanks that have previously been mentioned. One of these tanks produced a crop of corn during the summer when the analyses were made, the other tank was kept bare of vegetation.

Table 26. — Percentage of Carbon Dioxide in Air of Soil Planted to Corn and of Bare Soil

Date of Analysis	Planted Soil	Unplanted Soil	Difference
Aug. 19	3.42	2.45	.97
Aug. 23	3.53	2.00	1.53
Aug. 26	3.44	2.37	1.07
Aug. 30	3.03	2.04	.99
Sept. 2	3.28	2.17	1.11

It is apparent that the effect of the growth of plants has been to increase the amount of carbon dioxide in the soil air. The figures represent the period of the greatest production of carbon dioxide by the corn plant.

127. Production of carbon dioxide by microörganisms. — In addition to the carbon dioxide excreted from roots, there are large quantities produced by microörganisms that exist in soils. These organisms are concerned in the decomposition of organic matter, and one final product of such action is carbon dioxide. It has been estimated that in one acre of soil to a depth of sixteen inches, there are sixty-eight pounds of carbon dioxide produced by bacteria and fifty-four pounds excreted by roots during the growing season.

128. Solvent action of roots in other ways. — Many investigators think that the large quantities of mineral matter that plants remove from soils could not be obtained from the water solution even with the aid of carbon dioxide. Several different ways have been suggested by which plants may assist in rendering soluble the nutrients contained in soils. It will not be necessary to discuss these as there has been no definite and conclusive outcome to the investigation of the subject. The indications are, however, very strong that the plant aids in obtaining its food material in some way or ways other than by the excretion of carbon dioxide.

129. Difference in absorptive power of crops. — Crops differ greatly in their ability to draw nourishment from the soil. The difference between the quantities of nitrogen, phosphoric acid and potash taken up by a corn crop of average size and a wheat crop of average size is very striking. In Table 27 it may be seen that two tons of red clover contain three times as much potash, nearly ten times as much lime, and somewhat more phosphoric acid

than does a crop of thirty bushels of wheat, including the straw.

The ability of any kind of plant to secure nutriment from the soil depends on a number of factors which need not be discussed here. According to their ability in this direction, plants have been popularly classified as "weak feeders" and "strong feeders." To the former belong such crops as wheat and onions, which require very careful soil preparation and manuring. In the latter class are maize, oats and cabbage which demand relatively less care. In the manuring and rotating of crops, this difference in ability to obtain nutriment must be considered, in order not only to secure the maximum effect on the crop manured, but also to get the greatest residual effect of the manure on succeeding crops.

130. Substances needed by plants and substances merely absorbed. — Some substances found in soils and absorbed by plants are used for the formation of plant tissue, and hence are indispensable. Other soil constituents, although absorbed by plants to sufficient extent to be found in their ash, are not essential to a normal growth of crops. The substances that are essential are generally present in plants in considerable quantities, because they constitute a part of the plant tissue.

131. Quantities of plant-food materials removed by crops. — When crops are removed from the land, they carry in their tissues considerable quantities of plant-food materials. The drain on the total supply may be serious if the soil is not well supplied with these substances. The larger the yield of crops the greater the quantities of plant nutrients they are likely to contain. The following table shows the quantities of nitrogen, potash, phosphoric acid and lime removed from an acre of land by some of the common crops. The entire harvested crop is included:

TABLE 27. — NUMBER OF POUNDS OF NITROGEN, POTASH, LIME AND PHOSPHORIC ACID REMOVED FROM ONE ACRE OF SOIL BY CERTAIN CROPS

CROP	YIELD	NITROGEN	POTASH	LIME	PHOSPHORIC ACID
Wheat . . .	30 bushels	48	28.8	9.2	21.1
Barley . . .	40 bushels	48	35.7	9.2	20.7
Oats	45 bushels	55	46.1	11.6	19.4
Corn	30 bushels	43	36.3	—	18.0
Meadow hay .	$1\frac{1}{2}$ tons	49	50.9	32.1	12.3
Red clover .	2 tons	102	83.4	90.1	24.9
Potatoes . .	6 tons	47	76.5	3.4	21.5
Turnips . . .	17 tons	192	148.8	74.0	33.1

While these are only a few of the cultivated crops, they give some idea of the quantities of plant-food materials removed from soils by ordinary cropping. The nitrogen removed by red clover is partly taken from the air and consequently the draft on the soil supply is not so great as would be indicated by the figure here given.

132. Possible exhaustion of mineral nutrients. — Comparing the figures given above with those in Table 17 it is evident that there is a supply in most arable soils that will afford nutriment for average crops for a very long period of time. On the other hand, when it is considered that the soil must be depended on to furnish food for humanity and domestic animals as long as they shall continue to inhabit the earth, at least so far as is now known, the very apparent possibility of exhausting, even in a period of several hundred years, the supply of plant nutrients becomes a matter of grave concern.

The visible sources of supply to replace or to supplement the nutrients in the soil now cultivated are, for the mineral substances, the subsoil and the natural deposits of phosphates, potash salts and limestone; and for nitrogen, deposits of nitrates, the by-product of coal distillation and the nitrogen

of the atmosphere. The last of these is inexhaustible, and the exhaustion of the soil nitrogen supply, which a few years ago was thought by some to be a matter of less than half a century, has now ceased to cause any apprehension. The conservation or extension of the supply of mineral nutrients is now of supreme importance. The utilization of city refuse and the discovery of new mineral deposits are developments well within the range of possibility, but neither of these promises to afford more than partial relief. The utilization of the subsoil through the gradual removal by natural agencies of the topsoil will, without doubt, tend to constantly renew the supply. The removal of topsoil by wind and erosion is, even on level land, a very considerable factor. The large amount of sediment carried in streams immediately after a rain, especially in summer, gives some idea of the extent of this shifting. This affects chiefly the surface soil, and thereby brings the subsoil into the range of root action.

There is little doubt that a moderate supply of plant-food materials will always be available in most soils, but for progressive agriculture manures must be used.

QUESTIONS

1. How does the total quantity of plant-food materials in soils compare with the total weight of soil ?

2. Are the percentages of nitrogen, phosphoric acid and potash uniform in different soils, or do they differ ?

3. Is there a direct relation between the productiveness of a soil and its content of plant-food materials ?

4. What is meant by available and unavailable plant nutrients ?

5. Name some of the factors that influence the availability of plant nutrients in soils.

6. Why is it not always possible to determine by chemical analysis the degree of productiveness of a soil ?

7. Explain what is meant by the absorptive properties of soil for soluble fertilizers.

8. Explain what is meant by selective absorption.

9. Explain the availability of absorbed fertilizers.

10. What two constituents are removed in greatest quantity by drainage water from an unplanted soil?

11. Explain how roots aid in the solution of soil.

LABORATORY EXERCISES

Exercise I. — Soluble matter of soil.

Materials. — A very rich soil, filter paper and funnel, evaporating dish, flame, dilute hydrochloric acid.

Procedure. — Place a small amount of a rich soil on a filter paper held in a funnel and leach with distilled water, catching percolate in an evaporating dish. Evaporate percolate to dryness and examine residue. Is it large or small in amount? Treat with a few drops of dilute acid. Finally heat over a flame. Explain results. This soluble matter is the most valuable portion of the soil.

Exercise II. — Absorptive power of soil for dyes.

Materials. — Soil, filter paper, funnel, solution of gentian violet.

Procedure. — Place a small amount of soil on a filter paper in a funnel and treat with a solution of gentian violet. Note that the water comes through clear for a considerable period indicating the high absorptive power of the soil for this dye. The capacity of the soil to absorb soluble matter prevents heavy losses of plant-food materials.

Exercise III. — Selective absorption by the soil.

Materials. — Soil, filter paper and funnel, solution of gentian violet and solution of eosin.

Procedure. — Proceed in the same way as Exercise II, comparing the absorptive power of portions of the same soil for the two dyes. Note the difference. The soil varies in its absorptive power with different materials. For instance, the soil absorbs acid phosphate much more strongly than sodium nitrate.

Exercise IV. — Absorptive power of the soil for gas.

Materials. — A moist loam rich in organic matter, a flask or bottle, concentrated ammonia.

Procedure. — Place in a flask or bottle a quantity of moist soil. Pour in a few drops of ammonia. Note strong odor. Stopper bottle and shake. Allow to stand for half an hour with several shakings. Open and note odor.

The absorptive power of the soil for ammonia, oxygen and other gases is a very important function. Explain why this is true.

CHAPTER VIII

ACID SOILS AND ALKALI SOILS

SOME soils are termed acid, or sour soils. They are so called because they give the same tests with certain chemicals that are obtained with vinegar and other acids. A common test for acids is to bring them in contact with blue litmus paper, and if the material is acid the paper is colored red. Soils that are strongly acid will also do this. Another property of acid materials is that, if sufficient quick-lime is brought in contact with them they will no longer color blue litmus paper red. This may be tried by slowly stirring quick-lime into vinegar and testing it occasionally with litmus paper. If sufficient quick-lime be added to an acid soil, it will no longer turn blue litmus paper red.

Whether a soil is acid or not is a matter of practical importance, because some plants do not grow so well on sour soils as they do on soils that are neutral or alkaline; on the other hand some crops prefer an acid soil.

133. Nature of soil acidity. — There are two kinds of soil acidity (1) when acids are present that have been formed by fermentation of organic matter in the soil, (2) when there is a deficiency of such material as lime or potash. In either case the soil will color blue litmus paper red.

134. Positive acidity. — The condition of soil first mentioned above has been termed positive acidity. It arises from the decomposition of organic matter when soil conditions are not favorable to the proper breaking down of the intermediate substances. An insufficient air supply caused

by saturation or compaction of the soil, or a lack of lime, may lead to the formation of these acids. Acid soils to which certain organic acids have been added were found to be unfavorable to the growth of plants like wheat, while the same soil, to which lime had been applied, produced a much better growth. Lime overcomes the injurious effect of this kind of acidity.

135. Negative acidity. — When a soil contains no free acids but is sour in its relations to plant growth, it may be said to possess negative acidity. Negative acidity is counteracted by the application of lime just as is positive acidity. The condition that renders the soil acid is a lack of substances like lime, magnesia, soda and potash. Any one of these four substances is called a base. Lime, being the cheapest of these to apply, is the usual corrective. The injurious action of soil acidity on plant growth has been attributed to one or more of the following causes: (1) lack of lime to overcome organic acids when they are formed; (2) absence of sufficient carbonate of lime; (3) great absorbent properties that cause the soil to compete with plants in their attempt to draw plant-food materials from the soil.

136. Ways by which soils become sour. — In regions of ample rainfall there is always a tendency for soils to become sour, and unless they originally contain large quantities of lime, or are of recent formation, they are likely to be in need of lime. This tendency may be due to any one or more of the following causes: (1) removal of lime and similar substances in drainage water; (2) removal of these substances by plants; (3) accumulation of acids contained in fertilizers applied to the soil; (4) formation of organic acids from plant remains.

137. Drainage as a cause of acidity. — The chief cause of soil acidity is doubtless the removal of lime, magnesia, soda and potash from soil by the water that percolates through

the soil and passes off as drainage. The quantities of these materials that are annually lost from an acre of soil, as found by lysimeter experiments, are shown in Table 24.

It will be noticed that there is a much greater loss from the unplanted soil than from the planted. The quantities of these materials taken up by some crops is much less than the difference between the quantities in the drainage in the planted and unplanted soil, hence the growth of these crops on land is really a means of saving lime.

138. Effect of plant growth on soil acidity. — Plant growth may promote soil acidity in the following ways: (1) by removal of the bases in the ash of the plants; (2) by leaving in the soil the acids with which these bases were combined; (3) by formation of organic acids during decomposition of plant remains.

It will be seen from Table 27 that the quantities of potash and lime removed in crops of average size vary considerably and in some cases are very large. When, as in a state of nature, the vegetation on the land is returned to it after life ceases, and its organic material is again incorporated with the soil, there is no loss in this way, but in ordinary farming most of the above ground portion of the crop is removed from the land. The manure of growing animals returns to the soil only a small proportion of the lime that was originally in the plants because the animal has used it, and the potash is likely to be leached from the manure unless it is carefully handled.

Crops in growing remove more potash and other bases from the soil than they do the acid-producing substances, which latter are left in the soil and contribute still more to its tendency to assume an acid condition.

139. Effect of fertilizers on soil acidity. — It has been shown very conclusively that the continued use of considerable quantities of sulfate of ammonia on land may result in bring-

ing about an acid condition. In the case of this fertilizer the ammonia is absorbed either directly or indirectly and most of the sulfate, which is an acid, remains in the soil. Probably no other fertilizer is so active in producing acidity, but it is possible that sulfate of potash or muriate of potash or gypsum may, in less degree, have the same tendency.

The use of free sulfur for combating fungous diseases may also lead to the formation of a sour soil.

140. Effect of green-manures on acidity. — In soils deficient in lime the incorporation of green-manure crops has been thought to produce temporarily an acid condition. It is during the early stages of fermentation in the soil that the acids are formed. When further decomposition proceeds, the acids are broken up and acidity disappears. This condition has been noticed mainly in the South Atlantic states. Where it has been found to occur, there is some advantage to be gained from plowing under the green-manure as long as possible before planting the next crop.

141. Weeds that flourish on sour soils. — Whether a soil is acid or not will make a great difference in the kinds of plants that will thrive on it. Certain weeds will generally be found growing on sour soil and the presence of these in large numbers may be taken as evidence that the soil needs lime. Weeds that appear to flourish on acid soils may do so either because they are physiologically adapted to an acid condition, or because other vegetation does not thrive, and hence these particular weeds have less competition on this soil. The weeds that in one part of the country or another may be considered to indicate an acid soil are as follows:

Sheep sorrel	Corn spurry
Paintbrush	Wood horsetail
Daisy	Plantain
Horsetail rush	Goose-grass

142. Crops adapted to sour soils. — There are a considerable number of plants, other than weeds, that grow well on sour soils, some, in fact, thriving better when the soil is acid than when it is not so. The following is a list of those that have been found to be adapted to soils of this kind:

Blueberry	Rhode Island bent-grass	Rye
Cranberry	Cowpea	Millet
Strawberry	Soy bean	Buckwheat
Blackberry	Castor bean	Carrot
Raspberry	Hairy vetch	Lupine
Watermelon	Crimson clover	Serradella
Turnip	Potato	Radish
Redtop	Sweet potato	Velvet bean

This list affords a sufficient number of plants to permit of a largely diversified cropping system on sour soil, should it be undesirable, or very expensive, to put lime on the land. The considerable number of legumes in the list would admit of soil improvement through their use.

143. Crops that are injured by acid soils. — While there is a considerable number of agricultural plants that are adapted to sour soil, it is true that the greater number of the most important crops is injured by such soil. General farming can best be conducted on soil that is not greatly in need of lime. One reason for this is that the great soil-improving crops — red clover and alfalfa — are very uncertain crops on acid soils. The following plants are injured by sour soil:

Alfalfa	Pumpkin	Cucumber
Red clover	Salsify	Lettuce
Saltbush	Spinach	Onion
Timothy	Red beet	Peanut
Blue-grass	Sorghum	Okra

Maize	Barley	Tobacco
Oats	Sugar beet	Kohlrabi
Pepper	Currant	Eggplant
Parsnip	Celery	Mangel-wurzel
Cauliflower	Cabbage	

Some of these plants will grow well on soil that is too sour for other crops. For example, red clover will grow fairly well on soil that is too acid to raise alfalfa.

144. Litmus paper test for soil acidity. — This test is made with blue litmus paper, which is brought in immediate contact with wet soil. A rapid and decided change to red is taken to indicate an acid condition of the soil. Carbonic acid, which is always present in soils, but which is not injurious to plant growth, is supposed to give only a faint pink color to the litmus paper. Various ways of bringing the paper into contact with the soil have been proposed, among others the placing of filter paper or blotting paper between the soil and the litmus paper. It has also been pointed out that the acid perspiration of the fingers may lead to a mistaken conclusion that the soil is acid.

Much litmus paper is sold that is of very poor quality, and an effort should be made to obtain a good article. When good paper is used and the test is carefully made, the general experience has been that it is a fairly good, although not an infallible, guide to the need of a soil for lime.

145. Litmus paper and potassium nitrate. — This is performed in the same manner as the former litmus paper test, except for the substitution of a saturated solution of potassium nitrate instead of water for moistening the soil. It is a more delicate test than the one with litmus paper alone. The operation consists in working a small soil sample to a thick paste with a saturated solution of potassium nitrate

and applying the paper directly to the soil. If the soil is acid, the potassium will be absorbed and an acid or acid salt set free, which will act on the litmus paper, giving it a decided pink color.

146. The Truog test. — In this test solutions of calcium chloride and zinc sulfide are brought in contact with the soil to be tested and the mixture is boiled. If the soil is acid, a gas called hydrogen sulfide is formed and driven off with the steam. The presence of this gas may be detected by placing a strip of moist lead acetate paper over the mouth of the flask in which the soil and solutions are boiled. The lead acetate paper is rapidly darkened by the hydrogen sulfide gas as it passes out of the flask. Detailed descriptions of the methods for making these tests for soil acidity will be found in the laboratory exercises.

147. Alkali soils. — We have seen that every soil is constantly undergoing decomposition, by which process a very minute fraction becomes soluble every year. Ordinarily, in humid regions, this soluble matter is leached out by the rain water that percolates through the soil. In those parts of the world where the rainfall is very slight, and yet where decomposition of soil proceeds, there is a tendency for the soluble matter to accumulate in the soil where there is no drainage, or for it to move to places where seepage accumulates. A strong accumulation of such soluble matter is known as alkali because it usually has an alkaline reaction, *i.e.* it turns red litmus paper blue.

148. Nature and movements of alkali. — Because of its easy solubility, alkali may move from place to place or upward and downward in soils. During periods of drought it is carried upward by the capillary rise of the soil water, while during periods of rainfall it may move downward, where it is out of range of roots. The composition of alkali varies greatly in different regions. The main distinctions

are between white and black alkali. The former gets its name from the fact that when it accumulates on the surface of the ground, as is very common in a dry time, it has a white appearance. The latter, on the other hand, is black, because, owing to its caustic nature, it dissolves organic matter from the soil, which gives it a black color.

149. Effect of alkali on crops. — Both white and black alkalis are injurious to plant growth when present in large quantity, but black alkali is much more active in this respect, as it attacks plant tissue just as it does the organic matter in soils. White alkali injures plants by withdrawing water from the plant cells and causing the plant to wilt. The nature of the salts contained in the alkali, and the species and even the individuality of the plant, determine the amount of alkali that is required to destroy a crop.

150. Tolerance of different plants to alkali. — Some plants are better able to endure the presence of alkali in soil than are others. This is due, in part, to the natural resistance of the plant to the injurious effect, and in part to the rooting habit of the plant. Deep-rooted plants are, in general, better able to resist alkali than are shallow-rooted ones, probably because some part of the root is in a less strongly impregnated part of the soil.

Of the cereals, barley and oats are the most tolerant. Of the forage crops, a number of valuable grasses are able to grow on soil containing a considerable quantity of white alkali. Timothy, smooth brome-grass and alfalfa are among the cultivated forage crops most tolerant of alkali, although they do not equal the native grasses in this respect.

The resistance of a number of plants to white alkali, expressed in pounds to the acre to a depth of four feet, is as follows:

TABLE 28. — RESISTANCE OF CROPS TO ALKALI

Crop	Total Alkali	Crop	Total Alkali
Peaches . . .	11,280	Barley . . .	25,520
Rye	12,480	Grapes . . .	45,760
Apples . . .	16,120	Sugar beets .	59,840
Pears	20,920	Sorghum . .	81,360
Oranges . . .	21,840	Alfalfa . . .	110,320
		Saltbush . .	156,720

151. Irrigation and alkali. — Frequently the injurious presence of alkali in an irrigated region has been discovered only after irrigation has been practiced for a number of years. This is due to what is termed "rise of alkali," and comes about through the accumulation, near the surface of the soil, of salts that were formerly distributed throughout a depth of perhaps many feet. Before the land was irrigated, the alkali was distributed through a great depth of soil, but after water was turned on, this was dissolved, and later brought to the surface, as the soil was allowed to dry out. The upward movement in such cases exceeds the downward because the descending water passes largely through the non-capillary pore spaces, while the ascending water passes entirely through the capillary spaces. The alkali accumulates principally in the capillary spaces and hence is swept to the surface in large quantities by the upward movement of capillary water.

152. Removal of alkali. — There are several ways in which alkali may be removed from soil, among which are the following: (1) leaching with underdrainage; (2) correction with gypsum; (3) scraping; (4) flushing.

The first of these consists in laying tile drains, much as is done for draining land in humid regions, then flooding the land with large quantities of water, which dissolves the alkali

and carries it out through the drains. This is, by all means, the most effective way of removing alkali.

Gypsum has been used for converting black alkali into white alkali, which it does by inducing chemical changes in the alkali. This may well be used when black alkali land is to be drained.

Scraping consists in allowing alkali to accumulate at the surface of the soil and then removing it with a scraper. This is never a very effective treatment.

Flushing is accomplished by removing the surface incrustation with a rapidly moving stream of water instead of a scraper. Like the former method it is not usually an adequate treatment.

153. Control of alkali. — Instead of actually removing alkali its injurious action may often be kept in check by keeping it well distributed through the soil and not allowing it to accumulate near the surface. This may be done by controlling evaporation and by the cultivation of alkali-tolerant plants. The methods usually employed for retarding evaporation of moisture are generally applicable for controlling alkali.

Cropping with alkali-tolerant plants naturally suggests itself as a means of combating alkali where it does not exist to such an extent as to interfere with all crop production. As these plants remove considerable quantities of alkali in their ash, they also serve as a means of alkali removal.

QUESTIONS

1. Distinguish between positive and negative acidity in soils.
2. Describe three ways in which soil acidity may be injurious to plant growth.
3. State three ways by which the growth of plants on soil tends to make it become sour.
4. What is the effect on soil acidity of a continued use of ammonium sulfate ?

5. If green-manures are found to produce acidity on a particular soil, what precaution should be taken in using them ?

6. Name three or four weeds whose presence in large numbers indicates that a soil is acid.

7. Name six or eight crops that are adapted to growth on sour soils, and an equal number that are injured by a sour soil.

8. Describe the litmus paper test for the detection of a sour soil.

9. Describe the test with litmus paper and potassium nitrate solution.

10. State what is meant by an alkali soil.

11. Explain the difference between white and black alkali, and the effect of each on crops.

12. Name some of the crops most tolerant of alkali.

13. Describe four ways by which alkali may be removed from soil.

LABORATORY EXERCISES

Exercise I. — Acid soils in the field.

Plan a field trip to a soil known to be distinctly acid. Observe structure of soil, organic content, character of crop and, particularly, character of other vegetation. It might be well to make a collection of the plants which are supposed to indicate acidity. Take samples of this soil for future tests for acidity in the laboratory.

Exercise II. — Litmus paper with and without potassium nitrate.

Materials. — Litmus paper, acid soil, evaporating dish, a neutral potassium nitrate solution.

To prepare litmus paper boil litmus powder (1 part) with alcohol (2 parts) for five minutes. Allow to settle and pour off the alcohol, thus carrying away certain dyes of low sensitiveness. To the powder now add five parts of water. Boil 10 minutes and allow to stand overnight. Decant liquid and filter it. This gets rid of most of the carbonates. Now make acid with sulfuric acid and bring back to required tint with barium hydrate. Dip narrow strips of filter paper into the solution and dry on glass. When dry cut into strips of the required size.

Procedure. — Mix one portion of a distinctly acid soil to a thick paste in an evaporating dish with distilled or rain water. Allow to stand for a few minutes, then pat to a smooth surface and apply to it one end of a strip of litmus paper, leaving the other end free for comparison. Press paper closely in contact with soil.

Treat another small portion of this soil in the same way, using a neutral potassium nitrate solution instead of distilled water.

Observe the rate of change of color of the litmus paper with and without potassium nitrate.

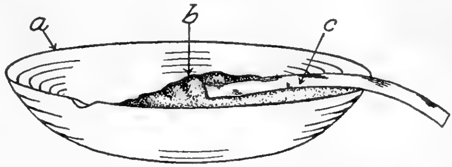


FIG. 21. — Procedure in the litmus paper test. (*a*) small evaporating dish, (*b*) soil worked to a thin paste with pure water or a neutral potassium nitrate solution, (*c*) the litmus paper in position, with one end free for comparison.

EXERCISE III. — Litmus paper test.

Materials. — Same as Exercise II.

Procedure. — Test a number of different soils. The students should be encouraged to bring in their own samples. Note whether there appears to be a difference in degree of acidity of these soils as indicated by the quickness with which the litmus paper turns red and the shade of red produced.

EXERCISE IV. — Test for soil carbonates.

Materials. — Soil, evaporating dish, dilute hydrochloric acid.

Procedure. — Treat a small portion of the soil to be tested with dilute hydrochloric acid. Effervescence indicates the presence of carbonates. A soil so reacting needs no lime. If no reaction occurs, test with litmus paper, as the soil may be alkaline, neutral or acid.

EXERCISE V. — Ammonia test for acidity.

Materials. — Soil, 8 oz. bottle, concentrated ammonia.

Procedure. — Place about 25 grams of soil in an 8 oz. bottle and add 10 c.c. of ammonia. Fill two-thirds full with distilled or rain water. Shake well and allow to stand overnight. A darkening of the supernatant liquid is an indication of the lack of lime.

This method is not a quantitative one because the degree of darkening of the liquid depends on the amount of organic matter present rather than the degree of acidity.

EXERCISE VI. — Zinc sulfide test for acidity. (See Fig. 22.)

Materials. — Soil, 250 to 300 c.c. Erlenmeyer flask, tripod and wire gauze, flame, calcium chloride-zinc sulfide solution, lead acetate paper.

The calcium chloride-zinc sulfide reagent is made up as follows: 50 grams of neutral calcium chloride plus 5 grams of zinc sulfide

is added to 250 c.c. of distilled water. The solution should be shaken well each time before using as the zinc sulfide is insoluble and tends to sink to the bottom of the vessel.

The lead acetate paper is made by dipping strips of filter paper into a saturated solution of lead acetate and drying.

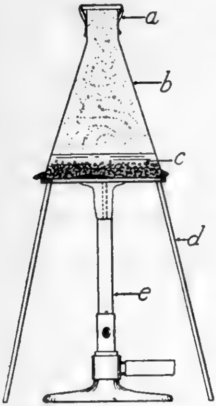


Fig. 22. — Apparatus for the zinc sulfide test for soil acidity. (*a*) lead acetate paper in position, (*b*) flask, (*c*) soil treated with calcium chloride and zinc sulfide, (*d*) tripod, (*e*) Bunsen burner.

Procedure. — Place in a 250 or 300 c.c. Erlenmeyer flask a 10 gram sample (well pulverized) of the soil to be tested. Now add 5 c.c. of the calcium chlo ide-zinc sulfide reagent, the former being in solution and the latter in suspension. Add 75 c.c. of distilled water. Place on a wire gauze over a flame and bring to boiling. Boil *exactly one minute*, being careful not to allow the sample to froth over.

The boiling having become constant and the CO_2 being driven off, lay over the mouth of the flask a strip of lead acetate paper moistened in distilled water. Allow it to remain there *exactly three minutes*. The test is now complete and acidity is indicated by the blackening of the paper.

Exercise VII. — Incrustation of "alkali" by capillary action.

Materials. — Sandy loam, lamp chimney, pan, salt.

Procedure. — Prepare a lamp chimney by neatly tying over the end two thicknesses of cheesecloth. Fill with sandy loam. Set the chimney now prepared into a solution of common salt. The salt solution will soon rise through the column by capillary action and evaporation will take place f om the soil. This will soon cause an incrustation of "white alkali" on the surface of the soil.

Explain this experiment in relation to irrigation practice and moisture conservation under arid conditions.

CHAPTER IX

THE GERM LIFE OF THE SOIL

Thus far we have been engaged in considering soil as lifeless material, on which plants are to be grown, but which in itself is inert and inanimate. Such a conception of soil is inadequate, for there is to be found in all arable land a vast number of forms of microscopic life that really constitute a part of the soil itself. From the standpoint of crop production they are of great importance, as we probably should not be able to maintain soil fertility without them.

Under germ life, as used in this chapter, are included bacteria, fungi, algæ, and some of the molds, but we shall in the main, dispense with these distinctions and use the term "germs" or "microörganisms" to cover all or any of them. In spite of what has just been said about the importance of germs in plant production, there are many that are injurious to plants both directly in the causation of disease, or indirectly by contributing to processes in soils that are detrimental to the conditions favorable to plant growth. In discussing the subject it will be convenient to take up first the soil germs that are directly injurious to plants. After that the subject will be discussed according to the processes in the soil with which microörganisms are concerned.

154. Microörganisms injurious to crops. — The soil germs that injure crops do so by attacking the roots. Those that attack other parts of plants may live in the soil during their spore stage but they are not strictly microörganisms of the soil. Some of the more common diseases produced by soil

germs are: wilt of cotton, cowpeas, watermelon, flax, tobacco, tomatoes, and other plants; damping-off of a large number of plants, root-rot and galls.

Some of the germs causing these diseases may live in the soil for many years. Some of them will die within a few years if the plants on whose roots they live are not grown on the soil, but others are able to maintain existence on almost any organic substance. Infection is carried in the soil, or by the roots of the plants themselves, consequently farm implements or manure may often be a means of spreading the germs.

For combating the difficulties caused by the germs, many methods have been tried with more or less success. Rotation of crops is successful in some cases, but in others entire discontinuance is the only remedy. The use of lime has been beneficial in the case of some diseases. Steam sterilization for greenhouse soils will hold in check a considerable number of diseases. Strains of cowpeas and cotton plants have been bred that are immune to the effects produced by some germs.

155. Germs not directly injurious to crops. — The part played by the microörganisms that affect the growth of crops may be roughly listed as follows: (1) action on mineral matter; (2) decomposition of non-nitrogenous organic matter; (3) decomposition of nitrogenous organic matter; (4) fixation of nitrogen from the air and its incorporation in the soil. Most of the processes involved in these transformations bring about conditions favorable to crop growth, but some of them are injurious, as, for instance, the formation of substances poisonous to plants and the liberation of nitrogen which escapes into the air. These injuries are, however, not direct effects of the germs on the crops, but indirect ones caused by the products of the organisms.

Bacteria, fungi, algæ and certain molds all play a part in these processes, but none of them so actively as do the bacteria. On account of the dominant part that bacteria

take in soil fertility some further description of their occurrence in soils will be given.

156. Numbers of bacteria in soils. — It is naturally to be expected that soils differ greatly in the number of bacteria that they possess. Where there is a large amount of easily decomposable organic matter, the number is great, and consequently in rich garden soils that have been heavily manured, or where the carcasses of animals have been buried the bacterial flora is dense. On the other hand, in very sandy soils, desert soils and water-logged soils, bacteria are few in number.

While there are usually many bacteria in fertile soil, it is not always the case that there are more in such soils than in less productive ones. The number of bacteria that a soil may contain cannot be considered a measure of its productiveness. The numbers of bacteria found in one gram of soil of different kinds and treated in different ways are given in the following table:

TABLE 29. — NUMBER OF BACTERIA TO A GRAM OF SOIL DURING SOME PERIOD OF THE GROWING SEASON

SOIL	DEPTH	CROP	NUMBER OF BACTERIA
Stiff clay	3 inches	Orchard in high state of cultivation. In cover crops	2,200,000
Adjoining soil above and of same character	3 inches	Meadow for twelve years	450,000
Of same type as above	3 inches	Vegetables and heavily manured	1,800,000
Same type as above	. . . . .	Scarlet clover plowed under and alternated with maize for ten years	3,360,000

157. Conditions affecting bacterial growth. — The environment is a controlling influence in the development of bacteria as it is of all organisms. Among the important environmental influences are the supply of air and moisture, the temperature, the presence of organic matter, and the presence or absence of acidity in the soil.

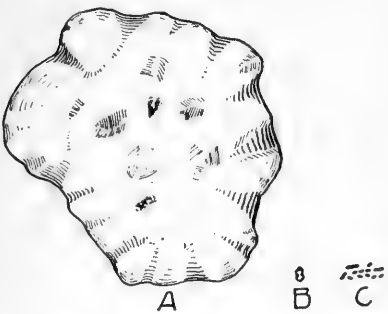


FIG. 23. — Diagram showing the relative sizes of bacteria and some soil particles. (A) a fine sand particle, (B) a large clay particle, (C) a few soil bacteria. All are magnified at the same rate.

158. Air supply. — While all bacteria require some air for their growth, certain of them are able to get along with much less than others. Those requiring an abundant supply of air have been called aërobic bacteria and those that thrive better on a small air supply are termed anaërobic. The bacteria that are of the greatest benefit to the soil are, in the main, aërobes, and those that are injurious in their action are chiefly anaërobes. Bacteria, however, have more or less ability to adapt themselves to a larger or smaller air supply. The fact that structure, texture and drainage are so largely instrumental in regulating the quantity of air in the soil makes them important factors in determining the kinds of bacterial processes that take place in a soil.

159. Moisture. — Like other forms of plant life, bacteria require moisture for their growth. A soil may become so dry that the number of bacteria is decreased, but owing to their rapid multiplication the number soon increases with a replenished moisture supply. An excess of water may decrease the number or change the character of the flora

by cutting off the air supply. A well-drained soil in good tilth affords the best moisture conditions for the development of desirable bacteria.

160. Temperature. — It is seldom that soil temperatures become sufficiently high to interfere with bacterial activity, and then it is only near the surface. Freezing does not kill most soil bacteria, but it renders them inactive during the frozen period. It is in the early spring that temperature is an important factor so far as its effect on bacteria is concerned. At that season it is desirable to warm the soil as rapidly as possible.

161. Organic matter. — Many forms of bacteria utilize the organic matter of the soil as a source of food supply. Others thrive without any organic matter. For the proper functioning of a normal bacterial flora there should be a good supply of organic matter in the soil.

162. Soil acidity. — Most of the useful bacteria make their best growth in a soil that shows no acidity. This is notably true of those bacteria that assist in the process of making organic nitrogenous matter suitable for use by plants, and also the symbiotic bacteria of alfalfa and red clover. One of the important effects of lime is the increased activity of beneficial soil bacteria.

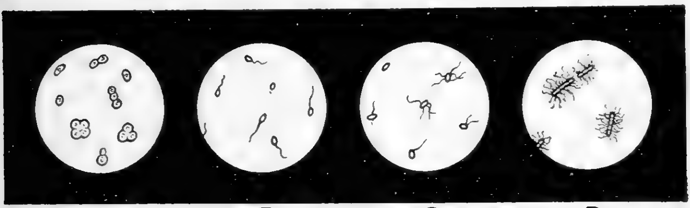
163. Bacteria in relation to soil fertility. — We have now discussed the conditions under which soil bacteria grow. The next step will be to describe the various processes by which they increase soil fertility and also, to some extent, by which they unfavorably influence soil productiveness. To do this they will be discussed in the order stated in § 155. The reader must, however, bear in mind that there are doubtless many bacteriological processes in the soil regarding which nothing is known.

164. Action on mineral matter. — There are, without doubt, microörganisms that act on mineral matter in soil,

attacking the insoluble substances and rendering them more soluble. The phase of this subject that is of most apparent agricultural importance is the effect of microörganisms on the very difficultly soluble rock or bone phosphoric acid, converting it into phosphoric acid available to plants. In laboratory experiments with pure cultures of bacteria these changes have been found to occur. There has also been found to take place a reverse process by which the more easily soluble phosphoric acid is converted into the less soluble one. There is, at present, no way by which man can control this operation in the soil. It has been held that the presence of a large quantity of organic matter will make the phosphoric acid of rock readily available. The results of experiments with raw rock phosphate and farm manure do not always confirm this idea. Under some conditions the dominant process may be the conversion of difficultly soluble into readily soluble phosphoric acid, while under other conditions the reverse may take place.

165. Decomposition of non-nitrogenous organic matter. — There is much organic matter on the surface or in the plowed soil that contains no nitrogen. The cell walls of plants, and the sugars, starch and fats of plants contain no nitrogen. These substances are broken down by bacteria, passing through different stages among which acids occur, and finally being resolved into carbon dioxide and water. We have seen that the plant uses carbon dioxide as food material, and we may now understand the cycle through which the carbon of this gas goes. Plants absorb carbon dioxide through their leaves, decompose it and use the carbon in their tissues. After the plant is dead, the tissues decompose and carbon dioxide is again formed and passes into the air. Just as higher plants live and grow by using carbon from carbon dioxide, so bacteria live and grow by using the carbon of plant tissues.

166. Decomposition of nitrogenous organic matter. — The main difference between the decomposition of non-nitrogenous and nitrogenous organic matter is that in the latter nitrogen and usually sulfur play a part. The sulfur is not of so much importance, but it is very necessary that we should follow the various processes through which nitrogen is transformed from organic substances into the final forms in which it is again used by plants or returned to the air. These processes will be treated under the following



A B C D

FIG. 24. — Appearance of some soil germs under the microscope. (A) free living nitrogen-fixing bacteria (Azotobacter), (B) bacteria that cause one step in the production of nitrates from ammonia (Nitrosomonas), (C) nitrogen-fixing bacteria from the nodules of leguminous plants (Radicicola), (D) ammonia-forming bacteria (Proteus vulgaris).

heads: (1) ammonification; (2) nitrification; (3) denitrification.

Organic nitrogenous matter when it first enters the soil as plant or animal remains or as solid farm manure or green-manure is largely in the form of what are known as proteids. As soon as such material is incorporated in any normal soil, decomposition begins and the rate at which it proceeds depends on the character of the soil in which the process is going on. There are several different forms of bacteria that are capable of decomposing proteins and there are always enough of these in any arable soil to do the work if the soil has the proper moisture, ventilation and heat and is not acid.

167. Ammonification. — Various intermediate products occur in the breaking down of proteids, but we are concerned chiefly with the product known as ammonia. This is the nitrogenous substance contained in many fertilizers, and it may be used by some crops directly as food material. Rice, for instance, and probably other swamp plants can use ammonia better than any other form of nitrogen. Even some upland crops like corn, peas, barley and potatoes can use it, but not as well as they can the form of nitrogen into which ammonia is transformed by the next fermentation, namely nitrification.

It may be well to say, in passing, that there are some other products intermediate between proteids and ammonia that are directly used by plants, and it is altogether likely that farm manure owes part of its great fertilizing value to some of these substances that it may possess.

168. Nitrification. — This is the final step in the preparation of nitrogen for use by most agricultural plants, for it is in the form produced by nitrification that nitrogen is most useful to most crops. This form is called nitrates. Like ammonification this fermentation goes on in any normal soil if the ammonia is there for it to work on, and also like ammonification the conditions of temperature, air supply, moisture and lime must be satisfactory or the process will be so slow that plants will suffer for nitrogen.

There has been some question as to whether heavy manuring with organic manures results in a decreased nitrification. While this may be the case where farm manure is used in very heavy dressings of as high as fifty to a hundred tons to the acre, as is sometimes done in truck crop gardening, it is not likely to be the case in soils in which ordinary field crops are grown.

169. Effect of soil aëration on nitrate formation. — One of the most important conditions that must obtain, if ammon-

ification and nitrification are to proceed rapidly, is an adequate supply of air in the soil and this can only be secured by thorough tillage. This is illustrated by an experiment in which columns of soil eight inches in diameter and eight inches high were removed from a field of clay loam and carried to the greenhouse without disturbing the structure of the soil as it existed in the field. At the same time vessels of similar size were filled with soil dug from a spot near by. These represented unaërated and aërated soils respectively, because one had been undisturbed, while the other had been thoroughly exposed to the air. Both were kept at the same temperature and moisture content in the greenhouse but no plants were grown in them. The production of nitrates was as follows:

TABLE 30. — FORMATION OF NITRATES IN UNAËRATED AND IN AËRATED SOIL

TIMES OF MAKING ANALYSES	NITRATES IN DRY SOIL, PARTS PER MILLION	
	Unaërated soil	Aërated soil
When taken from field	3.2	3.2
After standing one month	4.2	17.6
After standing two months	9.0	45.6

170. Effect of temperature on nitrate formation. — There is a considerable range of temperature through which the process of nitrate formation proceeds with more or less intensity. Freezing stops the fermentation, but does not kill the bacteria, whose activity is resumed when the temperature rises to about 40° F. and increases until a temperature approaching 75° to 85° F. is reached, after which the intensity gradually diminishes. At 110° F. and above, there is little formation of nitrates.

The more rapidly a soil becomes warm in the spring, the sooner will nitrates be formed. Crops like winter wheat will often begin growth before the soil is sufficiently warm to admit of the rapid formation of nitrates and, as winter rains will have leached from the soil nitrates that accumulated during the preceding year, the plants often suffer seriously from lack of nitrogen.

It is not often that the soil for several inches below the surface becomes hot enough, even in midsummer, to interfere with nitrate formation. Crops that make their growth in late spring or summer are not likely to suffer for nitrates unless the total supply of nitrogen is deficient.

171. Effect of sod on nitrate formation. — In soil on which there is a good stand of grass very little nitrate is ever found. Sod apparently has a depressing influence on nitrate formation. On the same type of soil as that used in the experiment last described, the average quantities of nitrates for each month of the growing season in the surface eight inches of sod land, as compared with corn land under the same manuring, were as follows:

Table 31. — Nitrates in Soil Under Sod and Under Corn

Month	Nitrates in Dry Soil, Parts per Million	
	Sod Land	Corn Land
April	8.9	—
May	3.0	17.1
June	2.4	40.3
July	4.0	194.0
August	5.4	186.7

There was more nitrogen contained in the corn crop than there was in the timothy crop, so that the larger quantity

of nitrates in the corn land cannot be attributed to failure of the plants to remove it. Grass appears to have a decidedly depressing effect on the process of nitrate formation, and this may be one reason why grass is generally a detriment to the growth of young orchards.

172. Depths at which nitrate formation takes place. — It is probable that the processes by which nitrates are formed are, in humid regions, confined largely to the furrow slice of soil. Nitrates found below that point have probably been, in large measure, washed down from above. The subsoil in such a region is not a very favorable medium for these processes. In arid and semi-arid regions, however, the case is different. Here the distinction between surface soil and subsoil is not so marked, and owing to the rich and porous nature of these subsoils nitrification may proceed at considerable depths.

173. Loss of nitrates in drainage. — It has already been shown that there is a large removal of nitrates in drainage water (§ 121). As nitrogen is the most expensive of fertilizer constituents every effort should be made to prevent this loss. A very effective way to do so is to have a crop growing on the land during all of the growing season. A comparison of the loss from the planted and unplanted soil, in the paragraph referred to, will show how effective a crop is as a means of preventing loss of nitrates in drainage water.

Hall states that nitrates formed during the summer or the autumn of one year are practically all removed from the soil of the Rothamsted fields before the crops of the following year have advanced sufficiently to use them.

174. Denitrification. — After nitrates have been formed by the processes that have just been described, there are other bacteria or some of the same bacteria acting under different conditions that attack the nitrates and convert

them into other substances. There are three different processes and three distinct products that may result. These are: (1) reduction of nitrates to ammonia; (2) reduction of nitrates to free nitrogen; (3) conversion of nitrates into organic nitrogenous substances. All of these fermentations result in a conversion of the more easily available forms of nitrogen into less available, and in the case of the production of free nitrogen there is a loss of nitrogen from the soil, as the free nitrogen is a gas and passes off into the air.

Most of the bacteria that effect these changes do so only when there is a limited supply of air, so that a thorough aëration of the soil practically prevents denitrification. Straw apparently induces denitrification when conditions are at all favorable for that process.

The addition of a nitrate fertilizer to a well-drained soil receiving farm manure is not likely to result in a loss of nitrates unless the dressing of manure has been extremely heavy. At the Rothamsted Experiment Station, where large quantities of nitrate of soda are used every year in connections with annual dressings of farm manure, the nitrate produces nearly as large an increase when applied to the manured as when added to the unmanured plat.

Very heavy applications of farm manure, of fifty tons to the acre or more, may temporarily interfere with formation of nitrates. The plowing under of large quantities of straw and even, under some conditions, green-manures may have this effect.

175. Nitrogen fixation. — Another and very important bacteriological process is the transfer of nitrogen from the atmosphere to the soil. This process is termed "nitrogen fixation" and it may occur either with the assistance of higher plants, or without. The first of these is called nitrogen fixation through symbiosis with higher plants, the second nitrogen fixation by soil organisms not associated with plants.

The importance of this process to soil productiveness may be realized when it is considered that nitrogen is the most expensive of all the ingredients of commercial fertilizers, and that many pounds to the acre may be secured by encouraging the growth of the bacteria concerned in the operation.

176. Nitrogen fixation through symbiosis with higher plants. — The value of certain plants as soil improvers has long been recognized, and within the last half century their ability to improve soil has been traced to their property of taking nitrogen from the air and leaving it in the soil. The plants that do this belong, with a few exceptions, to the family of legumes.

The method by which nitrogen is transferred from the air to the soil is not perfectly understood, but it appears to be somewhat as follows:

On the roots of leguminous plants are found nodules or tubercles, which are large enough to be seen with the naked eye, and in which live the bacteria that remove the nitrogen from the soil air and convert it into nitrogenous organic matter, that then becomes a part of the host plant. As a consequence legumes are very rich in nitrogen, and the tubercles contain an especially large quantity. When the roots and nodules decay and when the aboveground part of the plant is plowed under, the nitrogenous matter they contain becomes a part of the soil.

If the nitrogen-fixing bacteria are not present in the soil or other medium in which the legumes grow, no nodules will be formed and no atmospheric nitrogen will be fixed. The plant must then live on the combined nitrogen of the soil just as other plants do and consequently it does not serve to increase the store of soil nitrogen. In fact, the reverse occurs, for on account of the high nitrogen content of legumes, they withdraw, under these conditions, large

quantities of nitrogen from the soil. Even when the nitrogen-fixing bacteria are present, leguminous plants may draw much of their nitrogen from the nitrates in a soil that is rich in these substances. As a result, less nitrogen is taken from the air and if the crop is removed the quantity of nitrogen remaining in the soil may be no greater than before the legume was planted.

177. Soil inoculation for legumes. — After it had been discovered that leguminous plants acted as hosts for bacteria that draw nitrogen from the soil air, the idea at once presented itself that soils not containing these bacteria could be inoculated with them, and thus be made much more suitable to the growth of legumes. It has been found to be practicable to accomplish this inoculation by spreading on the land soil from a field on which the kind of legume it is proposed to plant has grown successfully. The fact that inoculation by means of soil from other fields may possibly transmit weed seeds and fungous diseases, and that it also necessitates the transportation of a great bulk and weight of material has led to numerous efforts to inoculate soil by means of pure cultures of bacteria. This has been fairly successful in recent years, but the surest way is by the use of soil. However, pure cultures may be obtained from most of the agricultural experiment stations and from the U. S. Department of Agriculture, Washington, D. C.

It must be borne in mind that when soil is used for inoculation it must come from a field that has produced a good crop of the same kind of legume that is to be planted on the inoculated field, also that the soil must not be allowed to become very dry, as that is likely to kill the bacteria. The inoculating soil is applied after plowing and is harrowed in.

If inoculation is to be successful, the soil on which the legume is to be planted must be of a nature favorable to the legume, otherwise growth will not be normal in spite of

inoculation. The conditions favorable for legumes are the same as for most upland crops, namely good drainage and good tilth, while for red clover, peas or alfalfa the soil should have an abundant supply of lime.

Not only is the yield of an alfalfa crop greatly increased by the presence of the nitrogen-fixing organisms and also

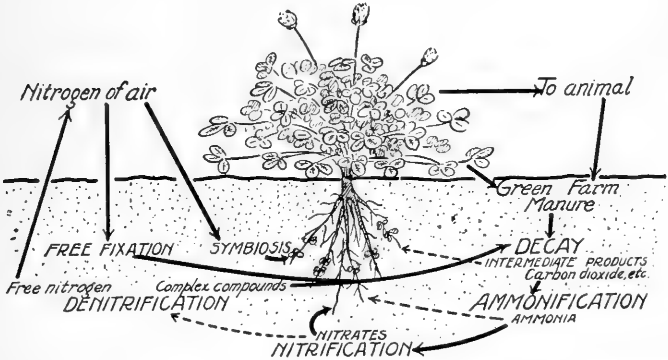


Fig. 25. — The cycle through which nitrogen passes in its movements among soil, plant, animal and atmosphere. Solid lines in the diagram indicate the usual transformations of nitrogen. Dotted lines indicate the occasional transformations.

of lime, but the percentage of nitrogen that the crop contains is thereby increased.

178. Nitrogen fixation by free living germs. — In addition to the nitrogen-fixing bacteria described above, there exist in many soils germs that are able to take nitrogen from the atmosphere and convert it into nitrogenous organic matter without the aid of a host plant. How extensively these organisms operate is difficult to say. In poor land they are often effective in recouping the supply of soil nitrogen, but it is doubtful to what extent they function in rich soil. At the Rothamsted Experiment Station one of the fields had been allowed to lie unused for many years because it was too

poor to cultivate. It grew up mainly to grass, with a very few legumes, and in the course of twenty years it had gained nitrogen at the rate of twenty-five pounds to the acre annually. With the exception of about five pounds to the acre that was brought down by rain, dust and the like, the accumulation was doubtless due to the free-living germs.

QUESTIONS

1. Explain the difference between the directly injurious and the indirectly injurious effect of soil germs on plant growth.
2. Are the numbers of bacteria in soils rather uniform, or do they vary greatly in different soils ?
3. Describe the relation of soil bacteria to the air supply.
4. Their relation to moisture.
5. Their relation to temperature.
6. Their relation to organic matter.
7. Their relation to soil acidity.
8. Their relation to soil fertility.
9. Describe the cycle through which carbon passes from plant to soil and back to air again.
10. Explain the fermentation known as ammonification.
11. Describe what is meant by nitrification.
12. How do soils of arid and humid regions differ in respect to the depths at which nitrate formation occurs ?
13. Why does nitrate formation not take place in early spring ?
14. Describe three fermentations by which the nitrogen of nitrates is converted into other forms.
15. Describe the two processes by which atmospheric nitrogen is fixed in the soil by germs.
16. Describe the cycle through which nitrogen passes from the plant to soil and back to plant again.

LABORATORY EXERCISES

Exercise I. — Test for nitrates in soil.

Materials. — A rich garden loam, a 500 c.c. vessel for mixing the soil and water, wooden stirrer, funnel and filter paper, hydrate of lime, water bath, ammonium hydrate solution, evaporating dish, phenoldisulphonic acid.

The phenoldisulphonic acid is prepared as follows: To 37 grams of concentrated sulphuric acid add 3 grams of pure crystalline phenol. Heat for six hours in a lightly stoppered flask set in boiling water.

Procedure. — To 50 grams of soil in the 500 c.c. container add 250 c.c. of distilled water. Add 1 gram of hydrate of lime to flocculate the soil. Stir three minutes and allow to stand 20 minutes. Pipette off 25 or 30 c.c. of the clear supernatant liquid and filter it. Evaporate 10 c.c. of the filtrate to dryness over a water bath in an evaporating dish. Moisten with a few drops of phenoldisulphonic acid and stir well. Allow to stand a few minutes. Dilute with a few cubic centimeters of water and neutralize with ammonia. The development of a yellow color is an indication of the presence of nitrates and its intensity is a measure of the amount.

Exercise II. — Test for ammonia in soil.

Materials. — A small portion of the soil solution obtained in Exercise I, and Nessler's solution.

The Nessler's solution is made as follows: To a 250 c.c. solution of potassium iodide (made by dissolving 63 grams in 250 c.c. of ammonia-free water) add a saturated solution of mercuric chloride until the precipitate nearly all redissolves. Now add 250 c.c. of a solution of potassium hydrate (150 grams to 250 c.c. of water). Make up the whole solution to one liter. Allow to stand until any precipitate has settled before using. Keep in well-stoppered bottle in the dark.

Procedure. — To ten cubic centimeters of the soil extract add a few cubic centimeters of Nessler's solution. The development of a light yellow is an indication of ammonia.

Exercise III. — Factors affecting nitrification.

Materials. — Same as Exercise I plus four 100 c.c. graduated cylinders. Use moist acid soil from beneath sod.

Procedure. — Place four 50-gram portions of a moist soil from beneath sod in 8-ounce wide-mouth bottles. Bring soil of bottle No. 1 to optimum moisture. Saturate soil of bottle No. 2 to give poor aëration. Thoroughly mix one gram of carbonate of lime to bottle No. 3 and one gram of lime plus one-tenth gram of ammonium sulfate with soil of bottle No. 4. Raise both to optimum moisture. Stopper all bottles lightly with cotton and allow to stand in a warm room for a week or ten days.

Develop nitrates from these samples as directed in Exercise I. Pour developed solutions into 100 c.c. graduates and dilute to a con-

venient mark. Compare the intensity of color from the various treatments and explain the results obtained. How may the results be applied to field practice?

Exercise IV. — Examination of legume nodules.

Visit fields of red clover, vetch, alfalfa, peas, etc., and with a spade carefully uproot some of the plants and search for nodules. Note the number, size and location of the nodules on the various legumes. If suitable specimens of roots bearing nodules are found it might be feasible to preserve them for exhibition purposes. They may be satisfactorily preserved in glass cylinders filled with water to which a few drops of formalin have been added. The cylinders should be tightly stoppered to prevent evaporation.

Exercise V. — Examination of nodule bacteria.

If the instructor has an oil immersion microscope available, with staining mixtures and other facilities for preparing slides of bacteria, this would be a desirable demonstration. The pupil would then gain a first hand knowledge of bacteria. Other soil organisms might also be mounted for class use.

Exercise VI. — Soil inoculation.

If the instructor could arrange in some way to coöperate with a near-by farmer in inoculating his soil by some of the means available for the purpose, this would be a valuable demonstration for the pupils to attend. Actually seeing a thing done is worth much more than mere class room study.

CHAPTER X

SOIL AIR AND SOIL TEMPERATURE

The volume of soil air depends on the volume of pore space that is not filled with water. It is, therefore, evident that ordinarily the non-capillary or larger spaces are the ones that contain air. It will be remembered that the most important conditions that favor a large pore space in soils are: (1) granular structure, (2) presence of organic matter. In any soil the pore space may change from time to time with the structure and the application of organic matter.

179. Soil air contained largely in non-capillary spaces. — The removal of water allows more space to be filled with air. Immediately after a heavy rain much of the pore space of the surface soil is filled with water. After this has had time to drain away only the capillary spaces remain filled, but capillary water is lost much more slowly. It is the non-capillary pore space that, during the greater part of the time, constitutes the air space of the soil. As a compact condition of soil results in smaller pore spaces and consequently in more capillary spaces, it causes a decrease in the volume of air.

180. There may be too much or too little soil air. — Soil air is a necessary constituent of a productive soil, as will be explained later, but it is not always the case that the more air space in a soil the better it is for crop production. Very large air spaces, like those found in a cloddy soil, allow the soil to dry out too readily. Up to a certain limit a good supply

of soil air is desirable, but there can be too much. On the other hand, there may be too little. It may be assumed that when a soil is in a compact condition it has an insufficient supply of air.

181. Movement of soil air. — The rate at which air moves through a soil depends largely on the size of the pore spaces, rather than on their aggregate volume. Movement of air is necessary to ventilate the soil, just as it is to freshen the air in a house in which many persons live, or a public hall in which people congregate. Among the factors concerned with the movement of soil air are (1) movement of water, (2) diffusion of gases, (3) some minor conditions, like differences in temperature between atmospheric air and soil air, periodic changes in atmospheric pressure and suction produced by wind.

182. Movement of water. — The movement of soil air caused by water is probably the most important of any. When rain falls, the surface soil first receives the water, which usually fills all of the spaces between the particles. As the water descends, air is driven from the pore spaces to make room for the water, the air escaping upward as the water goes downward, or else being forced out through the drainage channels below. The movement of air proceeds to the depth of the water table. Fully one-fourth of the air in a soil may be forced out by a normal change in the moisture content of a soil. As the soil dries out air returns.

183. Diffusion of gases. — Owing to the difference in composition between the atmospheric air and soil air, there is a tendency for them to mix, and this process would go on until the two had the same composition, were it not for the fact that gases are continually being formed in the soil and thus prevent the soil from attaining the same composition as the atmospheric air. The process of diffusion is, therefore, continuous.

The rate of diffusion depends on the total volume of the pore spaces and not on their average size. A soil in good tilth is therefore in suitable condition for permitting diffusion of atmospheric and soil air.

184. Composition of soil air. — The greater part of the soil air, like atmospheric air, is composed of nitrogen and oxygen. The principal difference between soil air and atmospheric air, in respect to composition, is that the former contains more moisture and more carbon dioxide. The moisture comes from evaporation of water in the soil. The carbon dioxide is produced for the most part by the germs in the soil and by roots. The following table shows how soils may vary in their content of carbon dioxide.

TABLE 32. — PERCENTAGE OF CARBON DIOXIDE IN AIR OF DIFFERENT SOILS AT SAME DEPTH

CHARACTER OF SOIL	PERCENTAGE COMPOSITION		
	Carbon Dioxide	Oxygen	Nitrogen
Forest soil	0.87	19.61	79.52
Clay soil	0.66	19.99	79.35
Asparagus bed not manured for one year	0.74	19.02	80.24
Asparagus bed freshly manured	1.54	18.80	79.66
Sandy soil six days after manuring	2.21	——	——
Vegetable mold compost	3.64	16.45	79.91

Soils that are high in organic matter and in which decomposition goes on readily, usually have a large quantity of carbon dioxide.

185. Production of carbon dioxide in soils. — It has already been shown that plant roots give off a considerable quantity of carbon dioxide throughout the growth of the

plant (§ 126). This, however, does not account for the gas that is formed in soils on which no plants grow. For this the germ life of the soil is responsible. These organisms consume fresh air and give off carbon dioxide in the process of their growth. In soils that contain a large and active population of microörganisms there is more carbon dioxide formed than in a more nearly sterile soil.

It has been estimated that in an acre of ordinary soil to a depth of four feet the germs produce between sixty-five and seventy pounds of carbon dioxide a day for two hundred days in the year, and that, during the growing period, the roots of oats or wheat would give off nearly as much in an acre.

186. Conditions that affect the quantity of carbon dioxide in soils. — As carbon dioxide is heavier than air, the quantity increases with depth. In warm weather more carbon dioxide is formed than in cold because the germs are more active. The soil moisture exerts an influence by furnishing the necessary moisture for the germs. A very dry or a very wet soil is not favorable to the production of the gas. More carbon dioxide is given off by roots during the blossoming period than at other stages of plant growth, consequently the carbon dioxide content of soil air is highest about the time the plants are in blossom.

187. Usefulness of air in soils. — The three gases, oxygen, nitrogen and carbon dioxide, that go to make up practically all of the soil air are useful in bringing about those processes that make soils fertile. Each one of these gases has its function in contributing to plant growth either directly, or by taking part in processes that render the soil more habitable to plants. The functions of each gas will be discussed separately.

188. Oxygen. — This constituent of soil air serves the following uses: (1) As a direct food material for plants,

and as a means of promoting in the plant the processes necessary to its growth. Roots of most crops must have access to a supply of oxygen.

(2) Decomposition of plant residues and other organic matter in soils requires the presence of oxygen, and without decomposition these materials would accumulate in the soil to the exclusion of higher plant life. Decomposition is also of use in the production of carbon dioxide, the function of which will be discussed later, and in the formation of compounds of organic matter with mineral matter, decomposition serves to increase the availability of mineral substances (see § 118).

(3) The process by which the nitrogen of organic matter is converted into nitrates can proceed only in the presence of oxygen.

189. Nitrogen. — Although not so essential as oxygen, there is at least one important service that is rendered by the nitrogen of soil air. This is to furnish the nitrogen-fixing organisms with a supply on which they may draw to produce the nitrogenous compounds that become incorporated in leguminous plants, or that are formed directly in the soil by the free-living nitrogen fixers.

190. Carbon dioxide. — The principal service that carbon dioxide renders is in acting as a solvent for the mineral matter of the soil. For this purpose it is itself first dissolved in soil water, in which condition it is a weak acid, but although weak, its universal presence and constant action make it an effective solvent. It dissolves from the soil more or less of all the nutrient substances required by plants in distinctly greater quantities than does pure water.

A number of experiments in which carbon dioxide was artificially brought in contact with soil on which plants were growing have resulted in producing larger crop yields than were obtained from soil not so treated. It cannot be con-

cluded from this that an artificial supply of carbon dioxide will always be beneficial, but it does indicate that carbon dioxide assists in making the plant nutrients more available, although in many soils the natural supply is sufficient for its maximum effect.

191. Control of the volume and movement of soil air. — It will be gathered from the preceding paragraphs that a good supply of air in soil with opportunity for its exchange with atmospheric air is desirable for a number of reasons. These conditions can be controlled by man to some extent. In fact those operations that usually promote tilth serve at the same time to effect a desirable condition of the soil with respect to air. The operations by which man may control soil air are as follows:

1. Tillage of all kinds, when properly done and at the right time, increases the volume of air in most soils by helping to form the crumbly structure, and by disposing of excess water.

2. Both farm manure and lime cause an increase in the carbon dioxide content of soil air, the former by contributing organic matter that finally decomposes, the latter by hastening decomposition processes.

3. Underdrainage by removing water from the pore spaces increases the volume of air and causes its movement.

4. Cropping produces channels through the soil where roots have decayed, and these openings, on account of their large number and ramifications through the soil, aid greatly in increasing the volume of soil air.

192. Soil temperature. — The temperature of the soil may influence plant growth both directly and indirectly. The direct effect is to be found in the plant itself, the roots of which require a certain degree of heat before they begin to function. A temperature somewhat above the freezing point is necessary for this purpose, some common plants

beginning growth slightly above that point, while others need several degrees higher temperature. This is also true of the germination of seeds. The optimum temperatures for both plants and seeds are considerably higher. A temperature may be reached at which both plant growth and seed germination may be inhibited, but soils rarely reach such a degree of heat, except at the immediate surface. The problem with soils usually consists in bringing them to a sufficiently high temperature in the spring.

The indirect influence of temperature is exerted through the germs that affect plant growth. These, like higher plants, require a certain degree of warmth before growth begins and a still higher temperature before they reach their full activity. It often occurs that crop growth is well under way before the soil is sufficiently warm for germs to function actively, and consequently growth is checked by the need of nitrates, which have not been formed in sufficient quantity on account of the low temperature. This condition is often demonstrated by the yellow color of the leaves.

193. Sources of soil heat. — The greater part of the heat that enters the soil comes directly from the sun. The other possible sources are the organic matter in the soil and heat from the interior of the earth. Heat produced by the decomposition of organic matter may sometimes be a factor when the proportion is large, as is the case in hotbeds and some gardens, but ordinarily it may be left out of consideration, as may also the heat transmitted from the center of the earth.

194. Relation of soil temperature to atmospheric temperature. — Changes in temperature of the atmosphere are transmitted to the soil, although the extremes are never so great in the soil as in the atmosphere, except at the immediate surface, and the extremes become less as the depth increases. In summer the temperature of the surface soil is

sometimes higher than the average temperature of the atmosphere, or even than the maximum air temperature. The soil below is cooler and continues to decrease in temperature as the depth increases. For that reason a cellar is usually cooler in summer than is the outside air. On the other hand, the soil does not become as cold as does the atmosphere in winter, and below a few feet, in temperate regions, the soil does not freeze. The following table gives the mean atmospheric temperatures, and the soil temperatures, at different depths by months throughout an entire year.

TABLE 33. — AVERAGE MONTHLY TEMPERATURE READINGS TAKEN AT LINCOLN, NEBRASKA

	Average of Twelve Years			
	Air	3 Inches Deep	12 Inches Deep	36 Inches Deep
January	25.2	27.8	31.2	38.5
February	24.2	27.3	30.2	35.5
March	35.8	37.2	35.4	35.8
April	52.1	56.0	49.3	43.8
May	61.9	67.5	60.7	53.3
June	71.0	78.0	69.9	61.3
July	76.0	83.6	75.7	67.4
August	74.5	81.3	75.7	69.8
September	67.6	73.4	69.2	67.6
October	55.5	58.4	57.8	61.3
November	38.7	40.9	44.7	52.2
December	28.3	31.4	35.2	43.3
AVERAGE	50.9	55.3	52.9	52.5
RANGE	51.8	56.3	45.5	34.3

195. Factors that modify soil temperature. — There are a number of conditions that exert an influence on the temperature of the soil, important among which are (1) the moisture content, (2) the color of the soil, (3) the slope of the land.

A wet soil is always a cold soil, because it requires about five times as much heat to raise the temperature of a pound of water through one degree of temperature as it does to heat a pound of dry soil to the same extent, and also because when the water becomes warm it evaporates and in so doing removes much heat from the soil. The evaporation of a pound of water from a cubic foot of soil will reduce the temperature of the soil about ten degrees Fahrenheit. Provision for having the water drain away from the land in the spring rather than evaporate will make a great difference in the warmth of the soil. A dark soil absorbs more heat than a light colored one. This is enough to make some practical difference in a region having a short growing season.

Land that slopes to the south absorbs more heat, in the North Temperate zone, than does land having any other slope, and the nearer the slope comes to making a right angle with the sun's rays the more heat it will absorb. An east or west slope receives more heat than does a north slope. For this reason a north slope is especially favorable for grass land, because grass is more injured by midsummer heat than by lack of sunshine.

196. Control of soil temperature. — As water is the substance in the soil most difficult to heat, it is evident that good drainage, that will remove the excess water derived from melted snow and ice, is the most effective means of warming land in the spring, in order that it shall be fitted for planting. If water can pass out of the soil by underdrainage it then becomes desirable to curtail evaporation, and this may be done by surface tillage. Evaporation of water removes, as we have seen, large quantities of heat. If water can be removed in any other way much heat is saved. In regions having hot spring days the loss by evaporation may be so large that more water is removed than is desirable and yet the soil may lack the necessary warmth.

Sandy soils are less likely to be cold in spring than are clay soils, because the former usually hold water less tenaciously. In vineyards a covering of stones on the soil has been found to facilitate the warming of the soil in the spring, but it is doubtful whether, in view of their other disadvantages, stones are desirable.

Good tilth is, next to drainage, the best aid to warming soil in spring, as it allows the water to pass down into the lower soil and thus decreases evaporation from the surface. Harrowing in the spring produces this result, while rolling, by compacting the surface, increases evaporation and cools the soil.

QUESTIONS

1. Describe the conditions that govern the volume of air in soils.
2. State the two principal factors that affect the movement of soil air.
3. How does the composition of soil air differ from that of atmospheric air ?
4. What are the sources of carbon dioxide in soil air ?
5. What are the functions of the oxygen of soil air ?
6. What are the functions of the nitrogen of soil air ?
7. What are the functions of the carbon dioxide of soil air?
8. In what ways may the volume and movement of soil air be controlled ?
9. Describe the direct and the indirect effect of temperature on plant growth.
10. What are the sources of soil heat ?
11. Describe three factors that modify soil temperature.
12. By what means may soil temperature be controlled?

LABORATORY EXERCISE

Exercise I. — Movement of soil air as influenced by texture and moisture.

Materials. — Dry sand, dry clay loam, 6″ funnels, cotton, aspirating bottles (10 liter).

Procedure. — Place a large funnel through the cork of an aspirating bottle, fill to the mark with water, as shown in Fig. 26. Place a small piece of cotton in the bottom of the funnel and fill with

a definite volume of sand. Now start aspiration by opening the water-cock of the bottle. When aspiration has become constant, note time necessary to draw one liter of air through the sand.

Using clay loam in place of sand, run the experiment again, bringing the water in the aspirating bottle up to its original mark before starting. The time necessary to pull a liter of air through each soil serves as a measure of the comparative rate of possible air movement through them.

Without removing the clay loam from the funnel, add enough water to bring it to optimum moisture condition. Repeat the test above. Explain results.

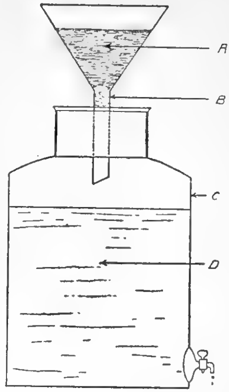


FIG. 26. — Apparatus for studying the relative rate of air movement through soils. (*A*) soil in funnel, (*B*) cotton support, (*C*) aspirating bottle, (*D*) water.

EXERCISE II. — The presence of carbon dioxide in soil air.

Materials. — Box of rich soil in good moisture condition, flask, limewater, tubes.

Procedure. — Equip a flask or bottle as shown in Fig. 27 so that air from the soil may be sucked into the limewater. The turbidity of the limewater indicates the presence of carbon dioxide.

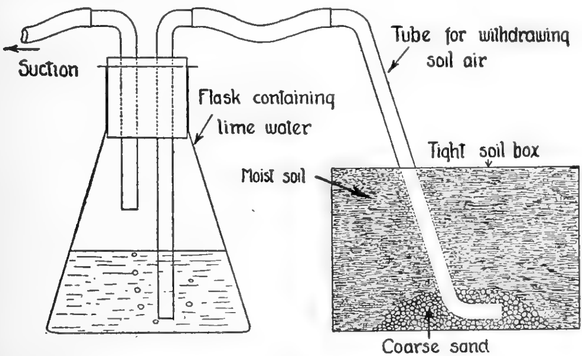


FIG. 27. — Apparatus prepared for the demonstration of the presence of carbon dioxide in soil air.

First pull atmospheric air into the limewater for five minutes. Note results. Now connect flask to tube extending into the soil and draw in soil air. What conclusions do you come to regarding the relative carbon dioxide content of soil air and atmospheric air? What is the function of carbon dioxide in the soil?

EXERCISE III. — Production of carbon dioxide by bacteria.

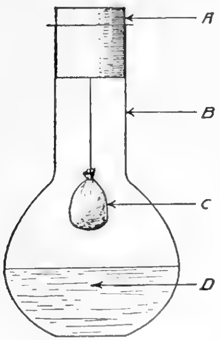


FIG. 28. — Production of carbon dioxide by germs in soil. (*A*) tight stopper, (*B*) flask containing limewater, (*C*) small bag containing moist soil suspended from stopper, (*D*) limewater.

Materials. — Flask, limewater and moist rich soil.

Procedure. — Place a small amount of limewater in a flask and then suspend in the flask over the limewater a bag of rich, moist soil. Stopper tightly and allow to stand for a week. Note the turbidity of the limewater. Explain the results.

EXERCISE IV. — Temperature and color.

Materials. — Coal dust and calcium hydrate. Thermometers.

Procedure. — Divide a small plat of smooth, level soil into three portions. Leave one part untouched, cover one with a thin coating of coal dust and the other with a coating of calcium hydrate. On a warm, sunny afternoon take the temperatures of each at one, three and six inches deep. Tabulate and give a practical explanation of the data obtained.

EXERCISE V. — Slope and temperature.

Materials. — Thermometers.

Procedure. — On a warm, sunny day take temperature at one, three and six inch depths on a south slope, north slope and level land, being careful to select for the observations soils having the same texture and moisture contents. Tabulate data and explain the practical relationships between temperature and slope of land.

EXERCISE VI. — Drainage and temperature.

Materials. — Soil, two jars, thermometer.

Procedure. — Prepare two large jars of moist soil. Stir one until two or three inches of the top soil is dry. Add water to the other until it is saturated. Set these jars of soil in the sunshine out of doors on a warm day. After two hours take the temperature of the two soils at one inch and three inches in depth. Tabulate data.

CHAPTER XI

NITROGENOUS FERTILIZERS

We have seen that nitrogen exists in soils in several different forms, as organic matter, ammonia and nitrates, and that it may be transformed from one to another of these, depending on the conditions that obtain in the soil itself. Fertilizers used for their nitrogen may have this nitrogen present in any one or more of these forms, and when incorporated with the soil, transformation will proceed according to the same laws that govern the soil nitrogen. This is important because nitrogen is more readily used by crops in some forms than in others.

197. Relative quantities of the different forms of nitrogen in soils. — One would naturally expect to find the greater part of the supply of soil nitrogen in the most stable forms, and this is, in fact, the case. The uncombined nitrogen of the air constitutes the largest supply because of its diffusibility with the atmospheric air. Next in quantity is the nitrogen of organic compounds, ranging from 0.05 to 0.3 percent or 1000 pounds to 6000 pounds to the acre in the furrow slice of ordinary arable land and slightly, but appreciably, soluble in water. In upland cultivated soils the nitrogen of nitrate salts forms the next largest supply, but rarely exceeds 20 percent of the total combined nitrogen of the soil.

In inundated soils, the nitrogen of ammonia salts and nitrites forms a larger proportion of the soil nitrogen than does the nitrate nitrogen, but in well-aërated soils these compounds exist in very small quantities.

198. Forms in which nitrogen is absorbed by plants. — The utilization of atmospheric nitrogen by leguminous plants and by a few others that have nodule-bearing roots has been established beyond question; but the extent to which this form of nitrogen may be utilized by other plants, or the kinds of plants that have the ability to use it, are subjects on which opinions differ. It is sufficient to say that such plants as red clover, alfalfa, peas, beans, vetch, and so on, are able to use atmospheric nitrogen. It must be remembered, however, that they also use nitrogen that is in the soil itself and that they may remove large quantities of this material.

199. Nitrates as plant-food material. — Most upland plants used in agriculture appear to absorb most of their nitrogen in the form of nitrates. This it will be remembered is the final form in which nitrogen appears when nitrogenous substances undergo normal decomposition in soil. The nitrogen of the various nitrogen carrying fertilizers is finally converted into nitrate in the soil.

200. Absorption of ammonia by agricultural plants. — Ammonia is rarely found in soils, except when they are saturated with water. Plants like rice, that grow on water-covered soil, can utilize ammonia; in fact, rice has been found to make a better growth on ammonium compounds than on nitrates. This is a case in which the plant has evidently adapted itself to its surroundings, for upland rice presumably uses nitrate nitrogen. However, some dry land plants can also use ammonia. It has been found, for instance, that peas obtained nitrogen as readily from ammonium salts as from sodium nitrate. On the other hand wheat plants, while able to secure some nitrogen from ammonia, have been found to grow much better when they could obtain nitrates.

201. Direct utilization of organic nitrogen by crops. — One of the early beliefs in regard to plant nutrition was that organic matter was directly absorbed by plants and that

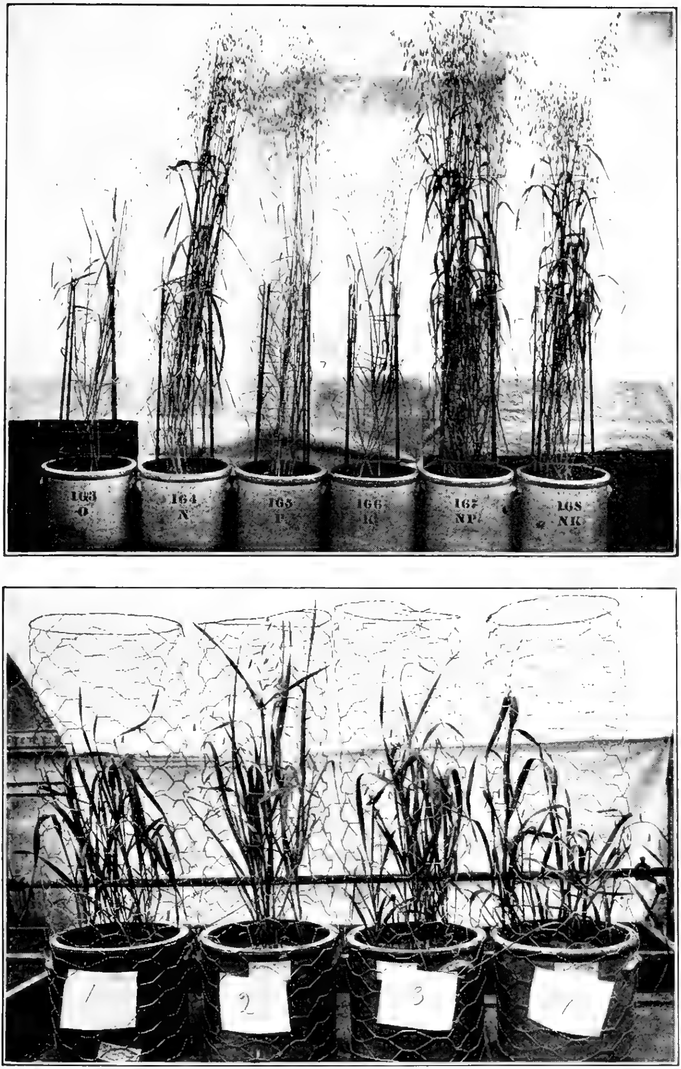


PLATE XII. FERTILIZER TESTS. — Some soils respond best to one fertilizer constituent, others to another. Note that the best growth of oats in the upper figure is in the vessels that received nitrogen. In the lower figure the best growth is in the vessel that received phosphoric acid.

it furnished their chief supply of food. Opinion afterwards swung to the opposite extreme, and it was generally held that no organic matter is absorbed by agricultural plants. Lately, however, it has been shown that many crops can use nitrogenous organic matter, and an organic compound called creatinin, that has been isolated from soil, was found to produce a better growth of wheat seedlings than did sodium nitrate. This may account in part for the high fertilizing value of farm manure. Many crops, especially among garden vegetables, are most successfully grown only when supplied with organic nitrogenous materials.

202. Forms of nitrogen in fertilizers. — There are many different kinds of material used to provide nitrogen in commercial fertilizers. Their value varies considerably, because the nitrogen in some is not so readily available as it is in others. In some the nitrogen is in the form of nitrate, in others ammonia, but most of the mixed fertilizers contain some or all of their nitrogen in the form of organic matter.

203. Nitrate of soda. — This material is found in natural deposits in northern Chili, where it is mined in enormous quantities and shipped to most of the European countries and to the United States. It is refined before shipment, reaching this country nearly 96 percent pure. Between 15 and 16 percent of the total material is nitrogen. The impurities are not of a kind to be injurious to plants.

This fertilizer is easily soluble in water and is readily absorbed by most farm crops. It is the most active form of nitrogen. Because it does not need to be acted on by soil organisms before being used by plants, it is of great value in starting growth in the early spring, before the soil is warm enough to cause a conversion of the nitrogen of soil organic matter, or of farm manure into nitrates. It will be remembered that nitrates are largely washed out of the soil during the fall and winter and that there is not usually enough

of this form of nitrogen to start plant growth early in the spring.

204. Crops markedly benefited by nitrates. — Winter grain is usually benefited by an application of 25 to 50 pounds to the acre of nitrate of soda about the time that growth begins in the spring. The phosphoric acid and potash fertilizers may be applied in the fall.

Timothy meadow responds wonderfully to a top dressing of nitrate when the plants first show signs of life. Not only is the yield of hay increased, but the sod is thickened, which increases its value as a manure for succeeding crops. Phosphoric acid and potash fertilizers should be applied at the same time. The following table shows the increased yield of hay and succeeding grain crops obtained from applications of nitrate fertilizer applied only to the grass crops. Note the increased yield of hay and grain from larger applications of nitrate when the other fertilizers are not increased, and also the striking effect of the better sod on the yield of corn, which crop was not fertilized. This offers a rational method for producing organic manure from mineral fertilizers.

TABLE 34. — YIELDS OF HAY AND GRAIN ON UNFERTILIZED SOIL AND ON SOIL FERTILIZED FOR HAY BUT NOT FOR GRAIN

PLAT No.	POUNDS FERTILIZER PER ACRE	YIELDS OF CROPS PER ACRE			
		Hay 3 Years	Corn	Oats	Wheat
		Tons	Bu.	Bu.	Bu.
720	No fertilizer	4.5	35.1	33.5	19.3
721	160 lbs. nitrate of soda 80 lbs. muriate of potash 320 lbs. acid phosphate	8.4	55.7	36.4	18.7
725	320 lbs. nitrate of soda 80 lbs. muriate of potash 320 lbs. acid phosphate	10.5	62.9	38.2	19.5
726	No fertilizer	4.2	33.4	29.7	22.8

By the time the wheat crop was raised the beneficial effect of the timothy sod had disappeared.

Many kinds of garden vegetables must have a rapid growth in order to have the succulence upon which their value largely depends. To secure this quick growth nitrate of soda gives an excellent form of nitrogen on account of its ready availability. As previously noted, however, it is not an adequate substitute for organic nitrogen for all kinds of garden crops.

205. Effect of nitrate of soda on soils. — Nitrates are easily leached from soils, and for that reason nitrate of soda should not be applied in the autumn as it will be lost, in large part, during the fall and winter. Even when applied preparatory to planting, it should not be used in excessive quantities at one time, but if large applications are necessary apply part after the plants have made some growth.

It has been found that the continued and abundant use of nitrate of soda causes some soils to become deflocculated, resulting in a puddled condition when the soil is worked wet and a cloddy condition when dry. This, however, is not likely to occur with any ordinary use of the fertilizer. On acid soils it serves a double purpose, for it tends to correct acidity.

206. Sulfate of ammonia. — The source of supply of this fertilizer is coal, which when distilled, as is done in the manufacture of illuminating gas, or in the production of coke, yields among other products ammonia from which sulfate of ammonia is made. The industry has grown enormously in recent years, but has by no means reached its maximum, as of the hundreds of thousands of tons of coal burned annually for the manufacture of coke in this country barely more than one-half is used for the production of ammonia. There are still great possibilities for obtaining nitrogen from this source.

207. Composition of sulfate of ammonia. — There is more nitrogen in a ton of this fertilizer than in any other. The commercial material usually contains about 20 percent of nitrogen, which is from eighty to one hundred pounds more than is contained in a ton of nitrate of soda. It is easily soluble in water, but when applied to soils the ammonia is absorbed, and probably very little of it is taken up directly by plants. On the other hand, the absorbed ammonia nitrifies readily, especially if there is plenty of lime in the soil, and the nitrates thus formed may readily be used by plants.

208. Action when applied to soils. — A pound of nitrogen in the form of sulfate of ammonia has slightly less value than the same quantity in the form of nitrate. If the soil to which it is applied is in need of lime, the value of the fertilizer will be less than if sufficient lime be present. It also tends to make a soil acid when used in large quantities for a long period. These two facts make it apparent that lime should be abundantly supplied to soils on which this fertilizer is used. Lime, whether it is applied to the soil or is naturally present, serves to neutralize the acid formed when the ammonia is converted into nitric acid by soil bacteria, which is the process by which nitrates are formed, and also to neutralize the sulfuric acid left in the soil when the ammonia is changed by this process.

The nitrates resulting from the fermentation of sulfate of ammonia are quickly leached out of the soil when no plants are growing on it; therefore sulfate of ammonia should not be applied at that time. In England the following losses of nitrogen occurred from plats on which nitrate and ammonium salts were used, and on which crops were grown. The term "minerals" is here used to mean phosphoric acid and potash fertilizers.

TABLE 35. — POUNDS OF NITROGEN IN DRAINAGE WATER FROM SOIL TREATED WITH NITRATE AND AMMONIA FERTILIZERS

TREATMENT	1879–1880		1880–1881	
	Spring Sowing to Harvest	Harvest to Spring Sowing	Spring Sowing to Harvest	Harvest to Spring Sowing
Unmanured	1.7	10.8	0.6	17.1
Mineral fertilizers only	1.6	13.3	0.7	17.7
Minerals + 400 pounds ammonium salts	18.3	12.6	4.3	21.4
Minerals + 550 pounds nitrate of soda	45.0	15.6	15.0	41.0
Minerals + 400 pounds ammonium salts applied in autumn	9.6	59.9	3.4	74.9
400 pounds ammonium salts alone	42.9	14.3	7.4	35.2
400 pounds ammonium salts + sulphate of potash	19.0	16.4	3.7	25.3
Estimated drainage in inches	11.1	4.7	1.8	18.8

These figures show a very considerable loss of nitrogen from the nitrogen-fertilized plats, with a somewhat greater loss from the nitrate-treated plats than from those receiving ammonia. Neither of these fertilizers is well designed to add to the total supply of nitrogen in the soil, for which purpose a less easily nitrifiable fertilizer must be used.

209. Cyanamid. — Within recent years it has been found possible to take nitrogen from the atmosphere and combine it with lime for use as a fertilizer. Two different materials are manufactured. One is called cyanamid, the other nitrate of lime. Both are produced by the use of powerful currents of electricity, but the processes are essentially different and only the cyanamid is now being manufactured in the United States, and it alone will be discussed in this book.

210. Composition of cyanamid. — The word cyanamid is

merely a trade name. Another name that has been used is lime nitrogen. The latter is good because it emphasizes the fact that the fertilizer contains lime, which is a point in its favor, as the lime helps to overcome soil acidity. There is about 26 percent of caustic lime in the fertilizer. However, in the quantities in which fertilizers are used the sweetening effect of the lime would not go very far. The fertilizer usually contains between 15 and 16 percent of nitrogen, which puts it on a par with nitrate of soda in this respect.

211. Changes in the soil. — Cyanamid must be decomposed in the soil before its nitrogen becomes available to plants. It is, therefore, not as rapid in its effects as is nitrate of soda, but resembles sulfate of ammonia in this respect.

Under some conditions products may be formed during its decomposition that are more or less injurious to plants. This is said to be true when the fertilizer is incorporated with water saturated soil or very acid soil. As decomposition proceeds these injurious substances are destroyed. In order to be sure that no injury will be done to plants, cyanamid should be applied at least a week before planting.

It is not well adapted to use on very sandy soils, nor does it give its best results when used as a top dressing, as it requires incorporation with the soil for its proper decomposition. Ordinarily its fertilizing value is not greatly below that of sodium nitrate, and is about equal to that of sulfate of ammonia.

212. Fertilizers containing organic nitrogen. — There are a great many materials containing organic nitrogen that are used as fertilizers. As many of them are of little or no value for other purposes they would be wasted if not used to benefit the land. There is very great diversity as to their fertilizer value, but in general the availability of the nitrogen to plants is less than that of nitrate of soda. In order that

their nitrogen shall become available, the substances themselves must decompose in the soil, the nitrogen undergoing the usual transformations.

Many of the organic fertilizers contain phosphoric acid, or potash, or both. These ingredients add to the value of the fertilizer. They will be discussed under the heads of (1) vegetable products, (2) animal products, (3) guano.

213. Vegetable products. — Among these are cottonseed meal, linseed meal and castor pomace together with other materials that are less used and that will not be discussed here.

The meals here mentioned are primarily stock-foods and are more profitably fed to live-stock, the resulting manure being applied to the soil, than used directly as fertilizer. Nevertheless, cottonseed meal is used extensively as a fertilizer and linseed meal to a less extent. The former is much used for tobacco of better grades and as a top dressing for lawn grasses, as it does not have the offensive odor that characterizes many of the organic fertilizers.

Cottonseed meal contains between 6 and 7 percent of nitrogen when free from hulls, and 4 percent when these are present. It also contains about 2.5 percent of phosphoric acid and 1.5 percent of potash.

Linseed meal contains about 5.5 percent of nitrogen, and between 1 and 2 percent of phosphoric acid and of potash.

Castor pomace, which is the residue after the extraction of castor oil from the beans, has a nitrogen content of between 5.5 and 6 percent, and a rather variable amount of phosphoric acid and potash.

214. Animal products. — These include the slaughter house products among which are red dried blood, with about 13 percent of nitrogen; black dried blood, with 6 to 12 percent nitrogen; dried meat and hoof-meal, with 12 to 13 percent nitrogen; tankage, of which the concentrated product has

a nitrogen content of from 10 to 12 percent, and crushed tankage, that has from 4 to 9 percent nitrogen. Leather meal and wool and hair waste may also be mentioned but they have only a small fertilizer value. Ground fish or fish waste is also sold as a fertilizer and usually contains about 8 percent of nitrogen.

Dried blood is the most readily decomposed of these products, and its nitrogen is in the most available form. It also contains a small quantity of phosphoric acid. It is slower in its action than either nitrate of soda or sulfate of ammonia. With this, as with all the animal products, the soil should be in a condition favorable to decomposition of organic matter and to the formation of nitrates.

Dried meat contains a high percentage of nitrogen, but does not decompose so easily as does dried blood, and is not so desirable a form of nitrogen. It may be fed to hogs or poultry to advantage, and the resulting manure is very high in nitrogen.

Hoof-and-horn meal is high in nitrogen, but decomposes slowly. Its nitrogen is less active than dried blood or meat. It is useful to increase the store of nitrogen in a depleted soil.

Tankage is highly variable in composition. The concentrated tankage, being more finely ground, undergoes more readily the decomposition necessary for the utilization of its nitrogen.

Leather meal and wool and hair waste when untreated are in such a tough and undecomposable condition that they may remain in the soil for years without losing their structure. They are not to be recommended as manures.

215. Fish waste. — The material sold under this name is usually waste from canning factories, and consists of the heads, tails, bones, entrails and all other discarded portions of the fish that are canned. As a fertilizer it acts very slowly and is not at all adapted to crops that make their growth in

the early spring. It is better adapted to sandy soils than to heavy ones.

216. Guano. — This was formerly a very important fertilizing material, but there is comparatively little of it imported into this country at present, because the world's supply is nearly exhausted. It consists of the excrement and carcasses of sea fowl. The composition of guano depends on the climate of the region in which it is found. Guano from an arid region contains much more nitrogen and potash than that from a region of more rainfall, because these constituents have been leached out of the latter. All of the plant-food materials contained in guano are in a readily available condition, and its fertilizing value is high.

217. Effects of nitrogen on plant growth. — The all important part that nitrogen plays in plant growth is that of an indispensable constituent of protein, which is the basic substance in every cell of every plant. It is therefore concerned in the formation of every part of the plant. If the supply of nitrogen is inadequate, the effect is to decrease the yield of the crop, especially the leaves, stems, stalks or straw, while the quantity of grain produced is not curtailed to the same extent. On the other hand, an excess of available nitrogen causes an abundant growth of the vegetative parts of the plant rather than of the seed or grain. As a result, in cereals the straw becomes so long and weak that the plants fall down or "lodge." Grass crops are less likely to suffer from an excess of nitrogen than are cereals, and nitrogen is particularly beneficial to the grasses. Many vegetables that are grown for their vegetative parts can utilize to good advantage a large quantity of nitrogen. If nitrogen is not present in sufficient quantity for cereals, the kernels are shriveled and light. There can be no doubt that the lack of a readily available supply of nitrogen at critical periods in the growth of plants is a frequent cause of curtailed crop yields.

Another effect of excess nitrogen supply is to delay the ripening of crops. This is often seen in orchards that receive clean cultivation throughout the summer. The large supply of nitrogen thus made available, as well as the moisture retained in the soil, serves to retard ripening and the immature wood is likely to be injured by winter temperatures. In regions having short, but usually hot seasons, cereals are sometimes delayed in ripening until injured by frost.

Sometimes the quality of crops may be injured by an excess of nitrogen. Barley deteriorates in its malting qualities, and peaches in flavor when too much nitrogen is supplied.

The percentage of nitrogen may be increased in some crops by supplying a large quantity of available nitrogen. Timothy hay responds in this way, as do many vegetables, and the straw and even the grain of cereals.

Resistance to disease is often decreased when nitrogen is abundant. This is familiarly exhibited in the ease with which a crop of wheat or oats on very rich soil will succumb to rust. There are numerous cases of this kind, probably due to a change in the physiological resistance of the plant to the diseases to which it is exposed.

218. Availability of nitrogenous fertilizers. — It has been pointed out that nitrates are the form in which nitrogen is most acceptable to the larger number of agricultural plants, and this being the case fertilizers having nitrates offer a very readily available form of nitrogen. Ammonium salts not being so readily appropriated by most plants require at least partial conversion into nitrates. Ammonia is absorbed by soil, but in its absorbed condition readily undergoes nitrification. However, there is apparently some loss or conversion into an insoluble condition, for experiments have generally shown that there is rarely quite as much nitrogen recovered by crops from sulfate of ammonia as from nitrate of soda. The organic nitrogenous fertilizers must un-

dergo ammonification and nitrification in the soil. Some of them decompose much more readily than others.

In order to ascertain the relative degree of availability of the nitrogenous fertilizers, experiments have been conducted by numerous investigators in which they have used one of these fertilizers on one or more plats of land, or in one or more vessels of soil, and other nitrogenous fertilizers in a similar way. It is, of course, always necessary that there shall be an abundance of all the other plant-food materials. These experiments were repeated for several years with different crops, at the end of which time a comparison was made of the yields of the crops on the soil treated with the different fertilizers. In Table 36 the results of some of these experiments are stated, with the yields obtained with nitrate of soda taken as 100 in each case.

Table 36. — Relative Effectiveness of Nitrogenous Fertilizers

Nitrogen Carriers	Wagner and Dorsch	Johnson and Others	Voorhees and Lipman
Nitrate of soda	100	100	100
Sulfate of ammonia	90		70
Dried blood	70	73	64
Bone meal	60	17	
Stable manure	45		53
Tankage		49	
Horn-and-hoof meal	70	68	
Linseed meal		69	
Cottonseed meal		65	
Castor pomace		65	
Wool waste	30		
Leather meal	20		
Dry ground fish		64	

While these experiments are helpful in giving an idea of the relative values of these fertilizers, they do not necessa-

rily hold for every soil. It will be noticed that there is considerable discrepancy in these results, but that is always to be expected. A fertilizer may have a more rapid rate of ammonification or nitrification than another fertilizer in one soil and less rapid in another soil.

219. Relative values of organic and inorganic nitrogenous fertilizers. — In the experiments cited the organic fertilizers were, in every case, less effective than the inorganic ones. However, the cost of a pound of nitrogen is generally more in the better class of organic fertilizers, like dried blood, than it is in the inorganic fertilizers, like nitrate of soda and sulfate of ammonia. This may be because of the demand of fertilizer manufacturers for a dry material for their goods, but the beneficial effect of the organic matter it contains may also be a factor in creating the demand for dried blood.

QUESTIONS

1. Name the forms in which nitrogen occurs in soils.
2. State what forms of nitrogen are absorbed by crops, and what differences exist between plants in this respect.
3. Name the fertilizer materials that contain nitrogen, and specify the form in which nitrogen occurs in each.
4. What crops are particularly benefited by nitrate fertilizers?
5. How is the nitrogen of nitrate and ammonia fertilizers likely to be lost from soils, especially if no crop is on the land?
6. How may danger arising from formation of poisonous products in the decomposition of cyanamid be avoided?
7. Describe the effects of nitrogen on plant growth.
8. State the order of availability of nitrogen in nitrate of soda, sulfate of ammonia and dried blood.

LABORATORY EXERCISES

Exercise I. — In Exercise V, Chapter I, an experiment designed to show the importance of the plant-food materials to plant growth was described. If this test has been properly conducted the influence of nitrogen upon plant growth will be clearly shown.

Exercise II. — Examination and identification of nitrogen fertilizers.

Materials. — Set of fertilizers (comprising sodium nitrate, ammonium sulfate, cyanamid, dried blood and tankage), evaporating dish, phenoldisulphonic acid, ammonia, funnel and filter paper, litmus paper, hand lens, flame.

Procedure. — It is well for the student to be able to identify the common fertilizers and to know a few practical tests when the identity is in doubt. The following outline is given with this end in view.

Sodium Nitrate

This fertilizer appears in clouded light yellowish crystals, soluble in water and rather deliquescent. It has no marked odor.

Hold a crystal in the flame. Note the brilliant yellow color. This is a test for the element sodium.

Test for the nitrate part of the fertilizer by moistening a crystal in an evaporating dish with a drop of phenoldisulphonic acid. Allow to stand a few minutes and then dissolve in a little water. Now neutralize with ammonia and obtain the yellow color characteristic of nitrates.

Ammonium Sulfate

This fertilizer is a light grayish colored salt, finely ground and soluble in water. Heat a little in an evaporating dish and note the odor of ammonia.

Cyanamid

Cyanamid is a fine, dry, black powder which carries besides its nitrogen compound, carbon and lime. The carbon may be tested for by rubbing the fertilizer between the fingers. Dissolve as much of the fertilizer as possible in water, filter and test the filtrate with litmus paper. It should be intensely alkaline on account of the lime it contains. The physical characters of the fertilizer are such as to make it easily recognized.

Dried Blood and Tankage

These materials can be easily identified and distinguished by their physical properties, especially if a hand lens is used. Considerable hair and bone is likely to be found in tankage. The odor of both is characteristic. Study each fertilizer until identification is easy.

Exercise III. — Comparison of fertilizer effects on plant growth.

Materials. — Fertilizers, flower pots, poor sandy soil, oat seed.

Procedure. — It may be of advantage to compare two or more of the nitrogen fertilizers with reference to their effect on plant growth. Fill flower pots with the same amount of a poor sandy loam after thoroughly mixing the fertilizer with the soil. Apply nitrogen fertilizers at the rate of 250 pounds per acre (1 of fertilizer to 10,000 of soil). Also add at the same time acid phosphate and muriate of potash at the rate of 1 to 5000 of soil respectively. One gram of lime per pot is also necessary. Leave one pot untreated with the nitrogen fertilizers as a check. Now plant oat seeds and bring the soil to optimum moisture content. When seedlings are a week old thin to proper number. Keep pots in suitable place and observe relative development of the plants under the different treatments.

CHAPTER XII

PHOSPHORIC ACID FERTILIZERS

Fertilizers commonly used in this country for their phosphoric acid may be divided into two classes, natural phosphate fertilizers and acid phosphate fertilizers. The former are in the condition in which they are found in nature, and are very difficultly soluble. The latter are merely the phosphate fertilizers that have been treated with strong acid, after which process they are readily available to plants. There is an intermediate form present in basic slag, which is not quite so available as the acid phosphate, but more readily available than the natural phosphate fertilizers. Natural phosphates, when in organic compounds, like bone, are more readily available than when in purely inorganic compounds, like rock.

220. Bone phosphate. — Most of the bone now used in fertilizers has been steamed or boiled, which removes the fat, and also the nitrogen that fresh bones contain. Fresh bones have a content of about 22 percent phosphoric acid and 4 percent nitrogen. Steamed bones have from 28 to 30 percent phosphoric acid and 1.5 percent nitrogen. Bone tankage, which has already been spoken of as a nitrogenous fertilizer, contains from 7 to 9 percent of phosphoric acid. Bone should always be finely ground, as it is then more readily available. It is a slow acting form of phosphoric acid.

221. Mineral phosphates. — These are found as natural deposits of rock in various parts of the world, some of the

most extensive being in the United States. When ground these are often called "floats." South Carolina phosphate contains from 26 to 28 percent of phosphoric acid. Florida phosphate exists in the forms of soft phosphate, pebble phosphate and boulder phosphate. Soft phosphate contains from 18 to 30 percent phosphoric acid, and because of its being more easily ground than most of these rocks it is often applied to the land without being first converted into an acid phosphate. The other two forms, pebble phosphate and boulder phosphate, are highly variable in composition, varying from 20 to 40 percent in phosphoric acid content.

Tennessee phosphate contains from 30 to 35 percent of phosphoric acid. In addition to these deposits, which have been extensively mined since their discovery, there have been found much larger deposits in the states of Idaho, Wyoming and Montana, but these have not yet been worked.

Apatite and coprolites are other forms of natural phosphate that are used as fertilizers. The former is found in Canada and the latter in England and France. They are not of much importance in the fertilizer business of this country.

222. Basic slag. — This is also called Thomas phosphate. It is a by-product in the manufacture of steel from pig iron rich in phosphorus. The phosphoric acid in this material is more readily available than that in the mineral phosphates, and when used as a fertilizer it does not require treatment with acid. It should be finely ground. It is not extensively used in the United States.

223. Acid phosphate. — The very difficultly soluble phosphates may be rendered more easily soluble by treatment with sulfuric acid. The product is called acid phosphate. When applied to soils it is much more available to plants than are any of the natural phosphates. Acid phosphates contain gypsum or land plaster as well as phosphoric acid. The proportion of the total quantity of phosphoric acid

originally present that is rendered soluble depends on the quantity of sulfuric acid added. In practice there is usually part of the phosphoric acid that is left in an insoluble form.

224. Composition of acid phosphate. — Acid phosphate made from animal bone is called dissolved bone and contains about 12 percent of available and from 3 to 4 percent of insoluble phosphoric acid. It also contains some nitrogen. When made from South Carolina rock, acid phosphate contains from 12 to 14 percent of available phosphoric acid, including from 1 to 3 percent of what is called reverted phosphoric acid. The best Florida acid phosphate contains as high as 17 percent, and the Tennessee acid phosphate 14 to 18 percent of available phosphoric acid.

225. Reverted phosphoric acid. — A change sometimes occurs in acid phosphate on standing, by which some of the phosphoric acid becomes less easily soluble, and to that extent the value of the fertilizer is lessened. This change is known as reversion. It is much more likely to occur in acid phosphate made from rock than in that made from bone. The quality of the material affects this change. The presence of iron and aluminum is supposed to increase reversion. Reverted phosphoric acid is probably not so available as the original acid phosphate.

226. Absorption of acid phosphate by soil. — Like many soluble substances acid phosphate, when applied to soil, is in part absorbed and held in a form in which it will not be leached out by the drainage water, but on the other hand, remains in a condition in which it is available to plants. Part of the soluble phosphoric acid may unite with iron or aluminum in the soil to form insoluble combinations. The richer a soil is in lime the less is the danger of forming these insoluble combinations. The availability of acid phosphate may continue for a second year, or even longer, after being applied to the soil.

227. Relative availability of phosphoric acid fertilizers. — The availability of these fertilizers has been casually mentioned as each was discussed, but a brief résumé will serve to make the matter more definite. Acid phosphate, including dissolved bone, is the most readily available of the phosphoric acid fertilizers. The reverted portion is more or less available, depending on the character of the original rock, and on the kind of soil to which it is applied. It is not as valuable as the soluble phosphoric acid. The insoluble portion has no greater availability than the rock from which the acid phosphate was made.

Next to acid phosphate in availability comes basic slag, then steamed bone and finally the rock phosphates.

Acid phosphate and basic slag may be used for top dressing grass or winter grains, but the other fertilizers must be incorporated in the soil in order to become available. It is necessary that they shall be acted on by the soil water having carbon dioxide in solution and possibly by other acids formed by the decomposition of organic matter.

228. Rock phosphate versus acid phosphate. — The question has frequently been raised in the last few years regarding the use of ground rock phosphate or floats as a substitute for acid phosphate. Which of these practices is the better must be largely determined by practical experiment, and by a study of the conditions under which floats become available.

It is urged in favor of floats that the price of phosphoric acid is much less in this form than in the form of acid phosphate, which is made by a more or less expensive process. It is further argued that even if much more material must be used in order to get a pound of available phosphoric acid the remainder stays in the soil to increase the total supply, and that gradually it will become available, finally perhaps reaching a point where no more need be applied.

On the other side is the well-established practice of using

acid phosphate, which dates back more than half a century, and has been accepted during that time as an improvement over the use of untreated bone, which was largely superseded when the process of making acid phosphate was invented.

On most soils acid phosphate apparently gives the more profitable immediate returns. On some of the rich soils of the Middle West, however, there is an indication that ground rock is a more economical source of phosphoric acid. Except in those regions where the superiority of floats has been demonstrated it is probably safer to use acid phosphate.

229. Effect of phosphoric acid on plant growth. — As has been previously stated, phosphoric acid is essential to the growth of plants. It is absorbed by plants at a fairly uniform rate throughout the period of their active growth, while nitrogen is largely taken up during the early stages of growth. Nitrogen and phosphoric acid are closely associated in plant development.

One very apparent effect of phosphoric acid is to hasten ripening. Cereal plants that receive an ample supply of available phosphoric acid reach the heading stage and final maturity sooner than do plants having an insufficient supply. This may be an advantage in a climate having a cool short season as it may help the crop to avoid frost in the fall. On the other hand this rapid ripening may limit the yield in a dry season, when there is a tendency for the crop to shorten its growing periods sufficiently to curtail the quantity of nutrients it absorbs and the food it elaborates.

Root development is always stimulated by available phosphoric acid. Young plants send their roots more deeply into the soil, which is an advantage in dry regions, where the top soil dries out quickly. Under any circumstances it increases the absorbing surfaces and benefits growth.

The quality of many crops, particularly of pastures, is improved by phosphoric acid. Animals reared on pastures

fertilized with phosphoric acid have been found, in a number of experiments conducted in Great Britain, to be more vigorous and to develop faster than when no phosphoric acid was applied.

By balancing the effect of nitrogen, phosphoric acid prevents an undue formation of straw, at the same time making it stronger; on the other hand, it increases the production of grain in cereal crops. In the same way it increases resistance to disease, probably by producing a more normal development of the plant cells.

An insufficient supply of phosphoric acid is less easy to detect than is an inadequate supply of nitrogen, because its effect is exercised on the production of grain or other seeds, rather than on the height and color of the plants. It requires some care, therefore, to detect a lack of phosphoric acid.

230. Plants particularly benefited by phosphoric acid. — The crops that respond particularly well to applications of phosphoric acid are turnips, barley, cabbage and other plants of that family, beets, spinach, radishes and lettuce. Corn is said to be well qualified to secure its phosphoric acid from the natural phosphates, as are also some of the legumes.

QUESTIONS

1. Name the natural phosphate fertilizers.
2. Why should natural phosphates be finely ground, when applied to the soil ?
3. How does basic slag compare in availability with rock phosphate ?
4. How is acid phosphate made, and how does it compare in availability with the natural phosphates ?
5. What is reverted phosphoric acid ?
6. Why is soluble phosphoric acid not readily leached out of soil after being applied as a fertilizer ?
7. What phosphoric acid fertilizers may be used for top dressing grass or other crops ?

8. Compare floats and acid phosphate as sources of phosphoric acid when fertilizing land.

9. Describe the effects of phosphoric acid on plant growth.

10. Name the plants that are particularly benefited by fertilization with phosphoric acid.

LABORATORY EXERCISES

EXERCISE I. — In Exercise V, Chapter I, an experiment was described that was designed to show the importance of some plant-food materials to plant growth. If this test has been properly conducted it should now be ready to show the actual effects of the phosphoric acid on crop development.

EXERCISE II. — Examination and identification of phosphate fertilizers.

Materials. — Set of fertilizers (consisting of ground bone, raw rock phosphate, basic slag and acid phosphate), hydrochloric acid, nitric acid, litmus paper, flame, test tubes, funnel and filter paper, ammonium molybdate solution.

The ammonium molybdate solution is made as follows: Dilute 50 c.c. of ammonia (sp. gr. .9) with 75 c.c. of distilled water. Dissolve in this 25 grams of molybdic acid. Pour this into a solution consisting of 175 c.c. of nitric acid (sp. gr. 1.42) diluted with 250 c.c. of water. Make the addition slowly with constant stirring. Allow to stand in a warm place for two days and then decant the clear supernatant liquid for use.

Procedure. — The fertilizers should be tested as described below and examined until their identification is easy and positive.

Ground Bone

Bone is usually ground to a coarse powder. It is dry and has a decided and characteristic odor. It is light gray in color, insoluble in water and has a characteristic appearance under the hand lens. Its physical characters are sufficient for identification.

Ground Phosphate Rock

Floats appear on the market as a light gray powder, insoluble in water and with little odor.

Dissolve a small amount in hydrochloric acid, heat and filter. Add ammonia until a precipitate appears. Dissolve it with a small amount of nitric acid. Then add ammonium molybdate. Heat gently. A yellow precipitate indicates the presence of phosphoric acid.

Basic Slag

This form of phosphoric acid appears as a dry, dark gray powder with a slight odor. If differs from cyanamid in that it does not stain the fingers upon handling. It is alkaline to litmus paper.

Test for phosphates as under phosphate rock.

Acid Phosphate

This fertilizer is a slightly deliquescent salt, brownish gray in color, and finely ground. Its odor is characteristic and serves to distinguish it from ground rock. Unlike floats it is partially soluble in water.

Dissolve a small amount in water. Filter and test the filtrate for phosphoric acid as described above.

Exercise III. — Comparison of fertilizer effects on plant growth.

Materials. — Fertilizers, flower pots, poor sandy soil, oat seed.

Procedure. — The comparison of the various phosphorus fertilizers upon crop growth, especially acid phosphate and raw rock, is a valuable experiment. Fill the required number of flower pots with the same amount of a poor sandy loam after thoroughly mixing the fertilizer with the soil. Apply the phosphorus fertilizers at the rate of 250 pounds per acre (1 of fertilizer to 10,000 of soil). Also add at the same time sodium nitrate and muriate of potash at the rate of 1 of fertilizer to 5000 of soil respectively. Apply one gram of lime per pot. Leave one pot untreated with the phosphorus fertilizers as a check.

Now plant the oat seed and raise the soil to optimum moisture. When seedlings are a week old, thin to required number. Keep pots under suitable conditions and observe relative development of the various treatments.

CHAPTER XIII

POTASH AND SULFUR FERTILIZERS

THE materials used as potash fertilizers, with a very few exceptions, are soluble in water. The matter of their relative availability is, therefore, of minor importance. When applied to soil, the potash salts are absorbed and held in a condition in which they leach out only in moderate quantities, but to a greater extent than does phosphoric acid. In the absorbed condition, however, they are readily available to plants.

It seems strange that with the many thousand pounds of potash contained in an acre of ordinary land, as may be seen by consulting Table 17, there should be any benefit derived from the few pounds of potash that are contained in a fertilizer. The fact that the fertilizer is effective gives emphasis to two facts: (1) the great insolubility of the soil potash; (2) the availability of the absorbed potash.

231. Stassfurt salts. — Most of the potash fertilizers used in the United States come from Germany, where there are extensive beds varying from 50 to 150 feet in thickness, lying under a region of country extending from the Harz mountains to the Elbe river and known as the Stassfurt deposits.

There are two forms in which potash is found in the Stassfurt beds. These are the sulfate of potash and the muriate of potash. It is necessary to distinguish between these two because the muriate, when used in large applications, has an injurious effect on certain crops, among which are tobacco,

sugar beets and potatoes. On cereals, legumes and grasses the muriate may be used without causing any injury, provided it is not brought in contact with the seed.

Comparatively pure forms of both muriate and sulfate of potash are on the market. The former contains about 50 percent of potash, and the latter about 48 to 50 percent. The sulfate is more expensive, but the muriate is equally good, except on the rather small number of crops that are injured by it.

The mineral produced in largest quantity by the Stassfurt mines is kainit, consisting of sulfate of potash and muriate of magnesia. It contains from 12 to 20 percent of potash. It has the same effect on crops as has the muriate of potash.

Kainit should not be drilled with the seed of any crop for when placed in direct contact with the seed injury may result. It is a wise precaution to apply the kainit a week or more before planting, if a heavy application is to be made.

232. Wood ashes. — The principal supply of potash in this country at one time was wood ashes. With the diminished consumption of wood as fuel, this source of potash has fallen off. Now wood ashes are only an occasional supply. In addition to potash, wood ashes furnish considerable lime and a little phosphoric acid. There is no muriate present and hence no injurious effect on plants, but it should not be brought directly in contact with seeds.

Unleached wood ashes contain 5 to 6 percent of potash, 2 percent of phosphoric acid and 30 percent of lime. Leached wood ashes have only about 1 percent of potash, $1\frac{1}{2}$ percent of phosphoric acid and 28 to 29 percent of lime. The unleached ashes are the more valuable.

Wood ashes are not only an excellent potash fertilizer, but are also useful to counteract acidity in soils, for which

purpose the lime in the ashes is even more effective than the potash because there is more of it.

233. Insoluble potash fertilizers. — Many rocks contain potash; for this reason there is a large quantity in soils. It has been proposed to grind the rocks that are richest in potash and to use them for fertilizer. Experiments with finely ground feldspar have been conducted by a number of investigators, but have given little encouragement for the successful use of this material. An insoluble form of potash is not given any value in the rating of a fertilizer.

234. Effects of potash on plant growth. — Plants require potash in order to make a normal growth. If no available potash is present, the elaboration of sugar and starch in plants is curtailed. Crops like potatoes and sugar beets, that produce much starch and sugar, are greatly benefited by an abundant supply of potash. It also has other functions in plants that make it indispensable. The grain of cereals fills out better and weighs more to the bushel and the straw is stronger, when a good supply of potash is available. Legumes are usually greatly benefited by potash. The large formation of sugar and starch affords the nitrogen-fixing bacteria the kind of food which they need, and to obtain which they live in symbiosis with the legume. If part of a clover and timothy field be well fertilized with potash, and another part receive none, it is likely to be the case that the proportion of clover to timothy will be much greater on the fertilized part of the field than on the unfertilized part, unless the natural supply of available potash is unusually large.

Potash tends to delay ripening of plants, but not to the same extent as does nitrogen. It also has an influence similar to that of phosphoric acid, in that it helps to overcome the tendency of nitrogen to make plants less resistant to disease.

235. Sulfur as a fertilizer. — It has been pointed out that sulfur is one of the substances essential to plant growth, but it has generally been considered that a sufficient quantity is contained in arable soils to supply the needs of crops, and that its application as a fertilizer is unnecessary. In spite of this there have been occasional experiments conducted from time to time in which sulfur, usually in the form of flowers of sulfur, has been applied to soils to ascertain its effect on plant growth.

236. Experiments with sulfur as a fertilizer. — Most of the experiments with sulfur have been conducted in Europe. In some cases the application of sulfur to the soil was found to be beneficial to plant growth, in other cases there was no effect. Where no result was produced, it is reasonable to believe that there was sufficient sulfur in the soil to supply the needs of the plants, and that any further addition was unnecessary. In those experiments in which sulfur was found to exert a beneficial action we cannot be certain that the increased plant growth was due to the larger quantity of sulfur obtained by the plants. Sulfur has been found to influence the action of the germs in soils, and it is possible that the plants grew better because the soil nitrogen was converted more rapidly into an available form by the stimulating effect of sulfur on the bacteria concerned in that process. Sulfur sometimes has other beneficial effects on plant growth. These secondary reactions sometimes lead to erroneous conclusions regarding the effect of a fertilizer.

237. Quantity of sulfur contained in crops. — It has been computed from the analyses of various plants that the quantity of sulfur, when figured as sulfur trioxide, that is removed from the soil by crops of ordinary size is sometimes greater, and sometimes less, depending on the kind of crop, than is the quantity of phosphoric acid removed by the same crop. This may be seen in the following table.

TABLE 37. — POUNDS OF SULFUR TRIOXIDE AND PHOSPHORIC ACID REMOVED FROM AN ACRE OF SOIL BY AVERAGE CROPS

CROP AND YIELD TO THE ACRE	CONTENT IN POUNDS TO THE ACRE	
	Sulfur Trioxide	Phosphoric Acid
Wheat (30 bu.)	15.7	21.1
Barley (40 bu.)	14.3	20.7
Oats (45 bu.)	19.7	19.7
Corn (30 bu.)	12.0	18.0
Alfalfa (9000 lb. dry wt.)	64.8	39.9
Turnips (4657 lb. dry wt.)	92.2	33.1
Cabbage (4800 lb. dry wt.)	98.0	61.0
Potatoes (3360 lb. dry wt.)	11.5	21.5
Meadow hay (2822 lb. dry wt.)	11.3	12.3

238. Quantities of sulfur in soils. — Analyses of virgin and cultivated soils have shown that there has been a depletion of sulfur in cropped soils. It also appears that the quantity of sulfur trioxide is probably not greater than the quantity of phosphoric acid in many soils, as may be seen from the following table, which is based on the analyses of a considerable number of soils.

TABLE 38. — POUNDS OF SULFUR TRIOXIDE AND PHOSPHORIC ACID IN SANDY AND CLAY SOILS

	POUNDS PER ACRE	
	Sulfur Trioxide	Phosphoric Acid
Sandy soils	1650	2610
Clay soils	2250	4230

239. Quantities of sulfur in drainage water. — Sulfur suffers a much greater removal in drainage water than does phosphoric acid. In lysimeter experiments this has been

shown to amount to from 31 to 56 pounds to an acre in one year, depending on whether the soil was limed or unlimed, cropped or bare, as shown in the following table.

TABLE 39. — POUNDS OF SULFUR IN DRAINAGE WATER FROM ONE ACRE OF SOIL

Treatment		Crops Grown				Sulfur (Pounds per Acre)	
Lime	Fertilizer	1910	1911	1912	1913–14	1911–14	Annual Average
None	None	Maize	Oats	Wheat	Timothy	127.2	31.8
None	None	None	None	None	None	176.1	44.0
None	None	Maize	Oats	Wheat	Timothy and clover	126.2	31.5
None	None	Maize	Oats	Grasses	Grasses	172.8	43.2
Lime	None	Maize	Oats	Wheat	Timothy	175.7	43.9
Lime	None	None	None	None	None	212.6	53.1
Lime	None	Maize	Oats	Wheat	Timothy and clover	164.2	41.0
Lime	None	Maize	Oats	Grasses	Grasses	151.0	37.7
None	Sulfate of potash	Maize	Oats	Wheat	Timothy	225.7	56.4
Lime	Sulfate of potash	Maize	Oats	Wheat	Timothy	248.1	62.0

With the rather large removal of sulfur in crops and drainage water, and a somewhat meager supply in the soil, it would appear likely that a deficiency might ultimately arise if there were no way in which sulfur could be added to soils. To offset the loss there is a certain quantity of sulfur, amounting to 6 or 8 pounds an acre, washed down by the rainfall each year. There is also a variable quantity of sulfur contained in some of the commonly used fertilizers.

240. Sulfur contained in fertilizers. — It has been rather fortunate perhaps that many of the fertilizers that are used because they contain other plant-food materials, also contain sulfur. This is true of farm manure and other animal and bird excrements, residues of crops, animal offal, gypsum or land plaster, acid phosphate, sulfate of ammonia, kainit, sulfate of potash and all the slaughter house products.

Whether, under ordinary methods of farming, it is desirable to use any fertilizer for the sulfur it contains has not yet been ascertained. It would appear, however, to be a subject worthy of consideration.

QUESTIONS

1. What occurs to a soluble potash fertilizer when applied to soil ?
2. With thousands of pounds of potash in an acre of soil, why do a few pounds of fertilizer increase the supply available to plants ?
3. Where are most of the potash fertilizers obtained?
4. Name the potash fertilizers.
5. Describe the effects of potash on plant growth.
6. Name some crops that are particularly benefited by potash.
7. Is there any indication that the use of sulfur as a fertilizer may be desirable ?
8. In what manures and fertilizers is sulfur contained ?

LABORATORY EXERCISES

Exercise I. — In Exercise V, Chapter I, an experiment designed to show the importance of three plant-food materials to plant growth was described. If this test has been properly carried out it should now be available to show the effects of potash on plant development.

Exercise II. — Examination and identification of potash fertilizers and sulfur.

Materials. — Set of fertilizers (consisting of muriate of potash, sulfate of potash, wood ashes and sulfur), nitric acid, hydrochloric acid, silver nitrate, filter paper and funnel, flame, litmus paper.

Procedure. — The fertilizers should be studied and tested until identification is sure.

Muriate of Potash

This salt is placed on the market as opaque crystals, soluble in water.

Dissolve a small portion of the fertilizer in water and filter. Add a drop of nitric acid and then silver nitrate. A white curdy precipitate indicates the presence of muriate.

Sulfate of Potash

This salt appears as a light yellowish powder, soluble in water and non-deliquescent.

Dip a crystal in hydrochloric acid and then place in the flame. The violet color is a test for potash.

Wood Ashes

Wood ashes are so characteristic as to need but little description. Leach a small portion with water and test the percolate with litmus paper.

Sulfur

Sulfur is a yellowish gray powder. It melts readily and burns with a bluish flame, giving a characteristic odor. It is insoluble in water.

EXERCISE III. — Comparison of fertilizer effects on plant growth.

Materials. — Fertilizers, flower pots, poor sandy soil, oat seed.

Procedure. — The study of the effect of the various potash fertilizers as well as of sulfur might be of value. Fill the required number of flower pots with the same quantity of a poor sandy loam after thoroughly mixing the fertilizer with the soil.

If the effects of the various potash fertilizers are to be compared add them respectively at the rate of 250 pounds per acre (1 of fertilizer to 10,000 of soil). Apply at same time sodium nitrate and acid phosphate at the rate of 1 of fertilizer to 5000 of soil respectively. Add one gram of lime to each pot. Leave one pot untreated with potash fertilizers as a check.

If sulfur is to be used apply it at the rate of 250 pounds per acre. Leave one pot with no treatment, have one to which only sulfur is applied, prepare a third with a complete fertilizer only (mixture of equal parts of sodium nitrate, acid phosphate and sulfate of potash applied at the rate of 1 of fertilizer mixture to 5000 of soil), and a fourth pot with sulfur plus the complete fertilizer.

Carry out the experiment as explained in Exercise III, Chapter XI, and observe results.

CHAPTER XIV

LIME

In the chapter on acid soils, reference was made to lime as a corrective of acidity. Lime is not a fertilizer in the same sense as are the substances that have been discussed in the last three chapters. It is, to be sure, an indispensable ingredient of plant tissue, but as it is generally present in sufficient quantity in arable soils, and as it is rather soluble, there is usually enough lime to fully supply plant growth, and this in spite of the fact that the soil may be greatly in need of liming. It is because of its effect on the soil, rather than directly on the plant, that lime is used as a soil amendment.

241. Forms of lime. — The forms in which lime is used on soils are (1) ground limestone, (2) marl, (3) air-slaked lime, (4) quick-lime and (5) water-slaked lime. The first three of these are similar in their effects, and are chemically alike, being what is termed carbonate of lime. Quick-lime and water-slaked lime have much the same action on soils, and are called caustic lime.

Quick-lime is made by burning limestone in a kiln. Quick-lime, when treated with water, forms water-slaked lime. Air-slaked lime is quick-lime that has been exposed to dry air until it has lost its caustic properties. Marl is found in beds in the earth, as is limestone, but it is softer than limestone. Like limestone it is ground before being used.

Owing to the combinations of the lime itself with water and gases in these various forms, there is required a greater weight of some forms than of others to give the same quantity

of lime. When the materials are fairly pure, the number of pounds of each required to give approximately equivalent quantities of lime are as follows:

Quick-lime	56 pounds
Water-slaked lime	74 pounds
Air-slaked lime, marl, ground limestone .	100 pounds

When applying lime to land, these relationships should be kept in mind. If it is a question of using quick-lime or ground limestone one must provide nearly twice as much limestone as quick-lime in order to apply an equal quantity of lime.

242. Absorption of lime by soils. — In the forms in which it is applied to soils, lime is not so soluble as potash fertilizers. When brought in contact with soil, the lime is absorbed and rendered still less soluble. It is, however, somewhat more soluble than soil potash, and drainage waters usually contain several times as much lime as potash. It is the soluble part of the lime that has the beneficial effect on crops and soils. The ways in which the benefit accrues are numerous and will be described in a number of the following paragraphs. Lime is usually applied in much greater quantities than are fertilizers, but the treatment is given only at intervals of four or five years.

243. Lime requirement of soils. — It is possible, by means of chemical methods, to ascertain how much lime a soil will absorb before it shows alkalinity due to the presence of an excess. Such a test is useful to indicate the quantity of lime that should be applied to a soil in order that it shall be at least temporarily adapted to the production of lime-loving plants.

The results of such a test are usually expressed in pounds of lime required to satisfy the absorptive properties of a certain number of pounds of soil, as for instance, 2,000,000 pounds. This will vary in different soils from none to several thousand pounds.

244. Effect of lime on tilth. — A clay or loam soil when in acid condition tends to become compact and difficult to till. The addition of lime to soil helps to bring about a granular formation of the small particles, and to give the soil better tilth. This effect has previously been noted in § 46.

245. Effect of lime on bacterial action. — Some of the most beneficial bacteriological processes are greatly favored by an abundant supply of lime in the soil. Important among these are the various processes involved in the formation of nitrates from organic forms of nitrogen. It seems also to be associated with the operation by which some legumes, for instance alfalfa, secure nitrogen from the air. The increased supply of easily available nitrogen is often reflected in the yield and nitrogen content of the crops, as well as in the percentage of nitrates in the soil. This is illustrated by an experiment in which alfalfa was raised on plats of land one of which was limed liberally and the other not limed. The hay was weighed when cut, and was then analyzed, as were also the weeds growing with the alfalfa. The soil was sampled and the nitrates determined. The soil was also allowed to stand for ten days at an optimum water content and a temperature suited to the production of nitrates, at the end of which time the quantities of nitrates formed were determined. The results are shown in Table 40.

TABLE 40. — THE EFFECT OF LIMING SOIL ON THE YIELD AND COMPOSITION OF ALFALFA RAISED ON IT, AND ON ITS NITRIFYING POWER

	LIMED	NOT LIMED
Yield of hay, pounds on plat	103	75
Percentage of protein in alfalfa	20.63	15.88
Percentage of protein in weeds	10.67	8.79
Nitrates in dry soil, parts per million	8.10	4.30
Nitrates produced in ten days, "	176.00	92.00

The effect of the lime was not only to increase the yield of alfalfa hay, but also its protein content, as well as that of the weeds growing with it. The rate of nitrate formation in the soil was also greater when limed.

246. Liberation of plant-food materials. — It has generally been held that the application of lime to soils renders some of the other plant nutrients more soluble by reason of the exchange of lime for these substances in the insoluble combinations found in soils. This has been discussed in section 115. There is little doubt that magnesia is thus rendered more available, but magnesia is rarely lacking. Potash is often said to be made soluble, but although such may be the case with some soils it is probably not true of all, and there is really little evidence to substantiate the claim in any case. The use of lime, under some soil conditions, may render phosphoric acid more available, probably by supplying a base more soluble than iron or alumina, with which, in soils deficient in lime, the phosphoric acid might otherwise be combined.

247. Effect on plant diseases. — The presence of abundance of lime retards the development of certain plant diseases, such as the "finger-and-toe" disease to which cabbages and some root crops are subject. On the other hand, it may promote some diseases, as, for example, potato scab.

248. The use of magnesian limes. — Some limestone contains a considerable proportion of magnesia. When grown in water cultures, many agricultural plants are injured when the proportion of magnesia is greater than that of lime. In soil, however, magnesia is not nearly as soluble as lime and consequently there may be many times more magnesia than lime present without as much actually being in solution. Hence it is seldom that magnesia is injurious, and magnesian lime may be used to overcome soil acidity except possibly in the few soils in which the ratio of magnesia to lime is already very high.

249. Caustic lime *versus* ground limestone. — As lime helps to correct soil acidity no matter in what form it is applied, there is little advantage in one form over another so long as it is remembered that 100 pounds of ground limestone are equivalent to 56 pounds of freshly burnt lime, and provided the cost, hauling included, is in that ratio. The greater ease with which ground limestone may be handled would, under these circumstances, give it the preference.

In respect to its effect on tilth, lime, in the caustic form, is apparently more effective than when in the form of ground limestone. For heavy clay soil, the compact and cloddy condition of which presents a serious difficulty, caustic lime is preferable. A comparison of these two forms of lime on a heavy clay soil is shown in the following table in which the average percentage increase in crops from the limed over the unlimed plats for a period of five years is stated.

TABLE 41. — AVERAGE PERCENTAGE INCREASE IN YIELD DUE TO CAUSTIC LIME AND GROUND LIMESTONE

FORM OF LIME APPLIED	POUNDS APPLIED PER ACRE	PERCENTAGE INCREASE IN YIELD OF CROPS
Caustic lime	3000	20.9
Ground limestone	6000	14.8
Caustic lime	1000	3.9
Ground limestone	2000	3.7
Caustic magnesian lime	2000	6.7
Ground magnesian limestone	3225	3.3

250. Fineness of grinding limestone. — The greater solubility of finely ground material, as compared with coarse, makes it desirable that limestone be at least fairly well pulverized before it is used. If it is so ground that all of the particles will pass through a sieve having 50 meshes to the

inch, it will probably be just as effective as if ground much finer.

251. Gypsum or land plaster. — In the early agriculture of this country, before ordinary commercial fertilizers were used, gypsum was a popular soil amendment. Its effectiveness has apparently decreased as the soils on which it was used have been longer under cultivation. It has generally been credited with liberating potash, and possibly as the soils have become more acid it has been less effective in this respect. At any rate, it is rarely used at present.

Gypsum has little effect on tilth and is not in any sense a substitute for caustic lime for that purpose, nor is it of any value to overcome soil acidity, as it contains a strong acid.

QUESTIONS

1. How does the need of a soil for lime differ, in principle, from its need for the other fertilizers we have studied ?
2. Name the forms in which lime is applied to soils.
3. Which of these are similar chemically and in their effect on soils ?
4. How is quick-lime made ? Water-slaked lime ? Air-slacked lime ?
5. How does the solubility of lime compare with that of potash, when both are absorbed by soil ?
6. What is shown by a chemical determination of the lime requirement of a soil ?
7. What is the effect of lime on some of the bacteriological processes in soil ?
8. How does lime affect the availability of certain other plant nutrients in soil ?
9. What is its effect on certain plant diseases ?
10. Discuss the use of magnesian limes.
11. Discuss the use of caustic lime as compared with ground limestone.
12. How does the fineness of grinding limestone affect its immediate usefulness ?
13. How does gypsum affect soil ?

LABORATORY EXERCISES

Exercise I. — A study of the forms of lime.

Materials. — Set of lime samples (ground limestone, marl, quick-lime, hydrate of lime and gypsum), hand lens, muriatic acid, litmus paper.

Procedure. — Study the various forms of lime until identification is easy.

Ground Limestone and Marl

Ground limestone can be detected by its physical condition, especially if a hand lens is used. It is practically insoluble in water. Its color varies from white to gray. The presence of carbonates may be detected by a few drops of dilute muriatic acid.

Marl is a soft powdery form of calcium carbonate. Its texture and the presence of shells and organic matter serve to distinguish it from ground limestone.

Quick-lime

Quick-lime appears on the market either in lumps or as a fine powder. It is very caustic and intensely alkaline to litmus paper. When in contact with water it heats and slakes, becoming hydrate of lime. This characteristic distinguishes it from the other forms of lime.

Hydrate of Lime

This form of lime is a white powder, soluble in water. Its sour taste serves to distinguish it from marl and limestone. It is alkaline to litmus paper.

Gypsum

This amendment is marketed as a grayish to white powder, insoluble in water. It is calcium sulfate. It does not react with acid as does the limestone nor with water as does the lump lime. Its lack of taste distinguishes it from hydrate of lime.

Exercise II. — Fineness of ground limestone.

Materials. — Samples of limestone, 10, 20, 40, 60 and 100 mesh sieves, balance and weights.

Procedure. — The fineness of ground limestone has a marked effect on its value. Weigh out 100-gram portions of the various samples of limestone and pass them through the sieves. Weigh

the resulting grades and calculate the proportion of the original sample passing through the different mesh sieves. Try to make a relative estimate of the value of the various samples on this basis.

Exercise III. — Effect of lime on biological action.

Materials. — An acid soil from under sod, two 8-ounce, wide-mouth bottles, hydrate of lime, large vessel for mixing soil and water, funnel and filter paper, evaporating dishes, water bath, phenoldisulphonic acid, ammonia, flame, two 100 c.c. graduated cylinders.

Procedure. — Place 50-gram samples of the acid soil in each of two 8-ounce bottles. Add and mix well with one gram of carbonate of lime. Bring the soils in each bottle up to optimum moisture content. Plug mouths lightly with cotton and set aside at optimum temperature for a week.

Now estimate nitrates in manner described in Exercise I, Chapter IX. A comparison of the results will show the influence of lime on nitrification. Apply these results to practical problems.

Exercise IV. — Flocculation by lime.

Materials. — Ground limestones and hydrate of lime ; large bottle for preparing soil suspension, two 100 c.c. graduated cylinders.

Procedure. — Prepare a soil suspension by shaking a heavy clay soil for 15 minutes in a bottle partially filled with water (one of soil to ten of water) after adding a few drops of strong ammonia. Allow to stand for two or three hours and then pour suspension into the cylinders. Fill to 100 mark. Now add to one a pinch of hydrate of lime and to the other the same amount of ground limestone. Shake well and allow to stand.

Watch closely and explain results. Apply the principle involved here to actual field practice.

Exercise V. — Flocculation by lime.

Materials. — Clay soil and hydrate of lime.

Procedure. — Prepare from one portion of clay soil a well-puddled ball. Add hydrate of lime to another portion of the clay soil (rate, 1 of lime to 500 of soil), and work into a ball after adding sufficient water. Allow the two samples to dry thoroughly. Crush each one. Note difference in crushing resistance and the structural character of each soil. Apply results to actual field practice.

Exercise VI. — Lime and the rotation.

The place of lime in a rotation depends on a number of factors. Discuss these with the student. Take a number of standard rota-

tions and decide where in the rotation the lime should come and why.

Encourage the pupils to obtain the rotations used on their home farms and discuss lime in relation to such rotations. It might also be well to visit some good farmer and discuss with him the form of lime he buys, how he applies it, what amounts he uses and where in the rotation he adds it to the soil. The practical phases of the use of lime are what the pupil should understand.

Exercise VII. — Problems — Forms of lime to apply.

In buying lime the form that will give the greatest amount of calcium for the money is usually purchased unless the flocculating effect of burnt lime is necessary. The relative value of the lime, the cost per ton, the freight and the cost of application must be considered. For a rough calculation 50 pounds of burnt lime is considered equal to 75 pounds of hydrate and to 100 pounds of ground limestone.

Problem 1. — A farmer located on land already sufficiently friable, wishes to apply one ton of burnt lime or its equivalent in other forms. Burnt lime costs him $5.00 per ton f. o. b., hydrate lime $4.00 and ground limestone $2.25 per ton. Freight is 25¢ per ton, as is also hauling and application together. Which form of lime should the farmer buy ?

Problem 2. — The next year the f. o. b. price of lime changed to $4.90, $3.00 and $2.00 for the burnt lime, the hydrate and the limestone, respectively. Considering freight and cost of haul and application the same as before, what form should be purchased ?

Problem 3. — This same farmer can purchase marl at $1.00 per ton, but he must load it himself and haul it three miles over a dirt road. It is impure, carrying only two-thirds the calcium that the limestone has. From conditions in your locality how would you consider the desirability of purchasing this form of lime as compared with those forms mentioned in Problem 2?

CHAPTER XV

THE PURCHASE AND MIXING OF FERTILIZERS

It is hardly three-quarters of a century since the fertilizer industry began its development. In that time the use of commercial fertilizers has spread to all the important agricultural states of this country. Their sale amounts to more than $110,000,000 annually, of which fully one-half is expended by the farmers of the South Atlantic states, in an area lying within three hundred miles of the seaboard. Nearly one-half of the remainder is purchased in the Middle Atlantic and New England states, while only about five percent is used west of the Mississippi river.

A large utilization of fertilizers in a region is often, but not always, an indication of an intensive agriculture. The importance of fertilizers in farm practice and the large expenditure that their use involves, together with the possibilities for profit, when they are properly used, make it desirable that those who utilize fertilizers should thoroughly understand the commercial, as well as the agricultural, values of these products.

252. Brands of fertilizers. — The various fertilizer constituents or carriers that have been described are purchased by fertilizer manufacturers, who mix them into various combinations, each of which is called a brand. Each of these brands usually contains nitrogen, phosphoric acid and potash, in which case it is called a complete ferti-

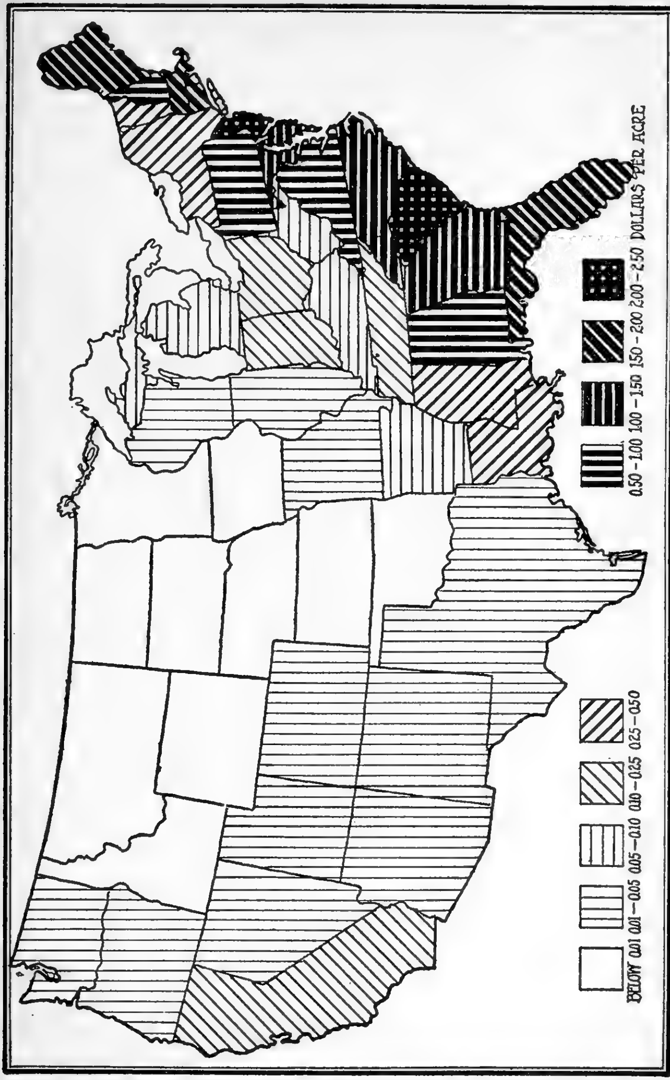


FIG. 29. — Extent to which fertilizers are used in the several states, based on the expenditure for fertilizers per acre of improved farm land, in 1909.

lizer, although occasionally a brand of fertilizer will have only two carriers. Each brand is given a trade name, frequently implying the usefulness of the fertilizer for some particular crop, but without reference to the character of the soil on which it is to be used. It is better, however, to purchase a fertilizer on the basis of its composition rather than because of its name. The composition of fertilizers for different crops will be discussed later (see § 261).

If, in compounding a fertilizer, those carriers are used that are difficultly soluble, the fertilizer is not so valuable as if composed of easily soluble substances. The solubility as well as the percentage of each ingredient should be known to the purchaser.

253. High-grade and low-grade fertilizers. — A fertilizer is known on the market as high-grade or low-grade, depending on the percentage of fertilizing constituents that it contains, or on the availability of its plant-food materials. Low-grade fertilizers cost less than high-grade because they contain less plant-food material or because they are less soluble, although the price of a pound of the plant nutrients may be no less, and, in fact, is usually more. The low-grade product is encumbered with a large amount of inert material, that adds to the cost of transportation and handling, without adding to the value of the fertilizer. For these reasons the cost of a pound of any one of the plant nutrients is usually less in high-grade than in low-grade goods. A ton of low-grade fertilizer may contain 500 or 600 pounds more inert material than a high-grade fertilizer, upon which freight must be paid, and which must be hauled from the station and spread on the field.

The following figures were obtained by tabulating one hundred and thirty brands of fertilizers analyzed at the Vermont Experiment Station.

TABLE 42. — COMPARATIVE VALUES OF LOW-GRADE, MEDIUM AND HIGH-GRADE FERTILIZERS

Fertilizer	Commercial Valuation	Selling Price or Total Price to Farmers	Excess Over Commercial Valuation	Cost of Putting $1.00 Worth of Fertilizer in Hands of the Farmer	Cost in Cents of One Pound of			Value of Fertilizer in Cents for Every Dollar Expended
					Nitrogen	Phosphoric Acid	Potash	
High grade .	$26.30	$38.93	$12.63	$0.48	28	5.7	6.3	67.6
Medium grade	18.22	30.00	11.78	0.65	31	6.3	7.0	60.6
Low grade .	13.52	27.10	13.58	1.00	38	7.6	8.5	50.0

In mixing fertilizers in a factory, it is customary to incorporate with the carriers of plant nutrients more or less material that has no influence on plant growth, but that serves to dilute the mixture and to prevent it from becoming damp by the absorption of moisture, and also to prevent the chemical interaction of the constituents. This material is called a filler.

254. Fertilizer inspection and control. — Most of the states have enacted legislation providing for the inspection and control of the sale of commercial fertilizers. Each brand of fertilizer, that sells for $5.00 or more a ton, must pay a state license fee and each bag must bear a tag stating the guaranteed percentage of nitrogen, phosphoric acid and potash that the fertilizer contains, and giving some information in regard to their solubility.

There is little uniformity in the requirements of the different states. In some states a very detailed statement of the composition of the fertilizer and the solubility of its constituents is required. The following information is called for by some of the states.

Percentage of nitrogen in the following forms:

In nitrates and ammonium salts. These are generally present in nitrate of soda and sulfate of ammonia. Their availability has already been discussed (see § 218).

Water-soluble organic nitrogen. This is probably not so readily available as the two former kinds, but differs little from them in this respect.

Active water-insoluble organic nitrogen. Although not directly available this becomes so quickly enough for the crop to which it is applied to obtain part of it.

Inactive water-insoluble organic nitrogen is that part of the organic nitrogen that is of little value for immediate plant growth.

Percentage of phosphoric acid in the following forms:

Water-soluble phosphoric acid, which is readily available (see § 227).

Reverted phosphoric acid. Not so readily available (see § 227).

Available phosphoric acid. This usually consists of the sum of the two forms mentioned above. Sometimes when this term is used no distinction is made between the water-soluble and the reverted, but this is not so satisfactory.

Insoluble phosphoric acid. This is slowly available, but in animal products, such as bone, tankage and other slaughter house waste, it becomes available more quickly than if present in rock phosphate. However, the analysis does not distinguish between the organic and inorganic carriers.

Percentage of potash in the following forms:

Soluble in water.

Present as chloride.

255. Trade values of fertilizer ingredients. — In the states having fertilizer inspection laws, it is customary for the officers in charge of the inspection to adopt each year a schedule of trade values for nitrogen, phosphoric acid and potash in each of the carriers ordinarily found in fertilizers.

These values are based on the wholesale market reports for six months preceding March 1 of each year, to which is added about 20 percent of the price, to cover cost of handling.

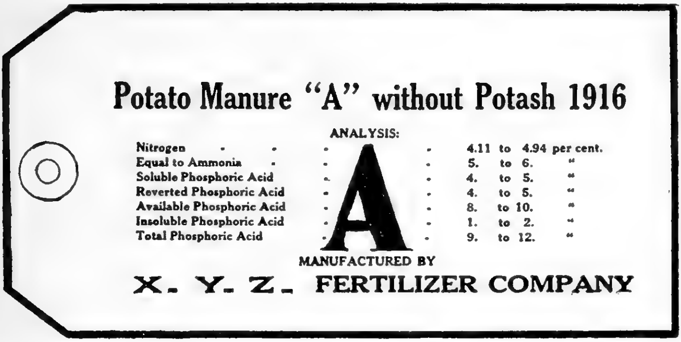


FIG. 30.—Tag representative of the kind often used on bags of fertilizer to state the percentages of their constituents.

The following values are for the year 1914.

TRADE VALUES OF PLANT NUTRIENTS IN RAW MATERIALS

	VALUE PER POUND IN CENTS
Nitrogen in nitrates	18.5
Nitrogen in ammonium salts	18.5
Organic nitrogen in dried and finely ground fish, meat and blood	20.0
Organic nitrogen in finely ground bone and tankage	19.0
Organic nitrogen in coarse bone and tankage	15.0
Organic nitrogen in castor pomace and cottonseed meal	20.0
Phosphoric acid, water soluble	4.5
Phosphoric acid, reverted	4.0
Phosphoric acid in fine bone, fish and tankage	4.0
Phosphoric acid in cottonseed meal and castor pomace	4.0
Phosphoric acid in coarse fish, bone, tankage and ashes	3.5
Phosphoric acid in mixed fertilizers, insoluble	2.0
Potash as high-grade sulfate, in forms free from muriate, in ashes, etc.	5.25
Potash as muriate	4.25
Potash as castor pomace and cottonseed meal	5.0

These values may be used by the consumer to calculate the wholesale cost of a fertilizer of guaranteed composition, which he can then compare with the retail price asked by the retail dealer. He may also compare the relative values of brands of similar composition offered for sale by different manufacturers.

256. Computation of the wholesale value of a fertilizer. — Suppose that we have the following statement of the analysis of a fertilizer.

	Per Cent
Nitrogen in nitrate of soda	1
Nitrogen in dried blood	2
Phosphoric acid, water soluble	6
Phosphoric acid, reverted	2
Potash, as muriate	10

The number of pounds of each constituent to a ton of fertilizer is then found by multiplying the weight of a ton of fertilizer by the percentage of the constituent, thus:

Nitrogen, as nitrate	$.01 \times 2000 = 20$ pounds per ton.
Nitrogen in dried blood	$.02 \times 2000 = 40$ pounds per ton.
Phosphoric acid, water-soluble	$.06 \times 2000 = 120$ pounds per ton.
Phosphoric acid, reverted	$.02 \times 2000 = 40$ pounds per ton.
Potash, muriate	$.10 \times 2000 = 200$ pounds per ton.

The trade values, as published by the fertilizer inspection officers, are then applied to the several constituents.

Nitrogen as nitrate	$20 \times \$.185$ =	$ 3.70
Nitrogen in dried blood	$40 \times \$.20$ =	8.00
Phosphoric acid, water-soluble	$120 \times \$.045$ =	5.40
Phosphoric acid, reverted	$40 \times \$.04$ =	1.60
Potash, muriate	$200 \times \$.0425$ =	8.50
		$27.20

Such a fertilizer will cost the consumer more than the figure derived in this way, because the entire cost of mixing and retailing must be added to it. It may serve as a basis for ascertaining whether it would not be more profitable

for a group of consumers to purchase the fertilizer ingredients in car-load lots and do the mixing themselves.

It must also be remembered that this is the commercial value and not necessarily the agricultural value, which latter is determined by the profits from its use, and will depend on many factors.

257. Home mixing of fertilizers. — There is a large margin between the trade value of fertilizer ingredients and their retail price as sold by the dealer. The cost of the raw materials often doubles in the process of mixing and retailing, with the necessary transportation. It has been demonstrated that the raw materials may be purchased from the wholesale dealer and mixed by the consumer at a considerably lower cost than if purchased mixed from the retail dealer, and that the results are fully as satisfactory.

Other advantages from home mixing are that it permits the farmer to use exactly the proportion of the several constituents that he desires, and that it makes unnecessary the handling of a large amount of inert materials frequently contained in mixed fertilizers. It is thus possible for him to ascertain, by field tests, the best proportions of the various fertilizer constituents to use on his own land for each of the crops he is growing. This knowledge makes it possible to decrease greatly the expenditure for fertilizers.

258. Fertilizers that should not be mixed. — Because fertilizers consist of chemicals, some of which react on each other to form compounds different from those in the original substances, it is unwise to mix certain of these carriers. The result may be to convert soluble nutrients into insoluble ones, or to cause the loss of some constituent in the form of gas. If one is to mix his own fertilizers he must know what materials should not be brought in contact. The following are some of the common carriers that should not be mixed:

Caustic lime Wood ashes Basic slag	with	Acid phosphate Dissolved bone
Cyanamid Caustic lime Wood ashes Basic slag	with	Sulfate of ammonia Slaughter house waste containing nitrogen Farm manure

The following mixtures should be applied immediately:

Caustic lime	with	Nitrate of soda Muriate of potash Kainit
Acid phosphate	with	Nitrate of soda or ground limestone.

Cyanamid should not be mixed with acid phosphate if there is more than one part of the former to ten of the latter.

259. Calculation of a fertilizer mixture. — In deciding on the composition of fertilizers the best and simplest way is to consider them according to the percentage of each of the three constituents, nitrogen, phosphoric acid and potash, they contain. If we decide to use a 3–8–5 fertilizer, the next step is to calculate how many pounds of each of the carriers of these substances must be used for each ton of the complete fertilizer, and how much filler must be added. Suppose we have on hand the following carriers:

Nitrate of soda containing 15 percent nitrogen
Acid phosphate containing 14 percent available phosphoric acid
Muriate of potash, containing 50 percent potash

The first step is to calculate the number of pounds of nitrogen, of phosphoric acid and of potash in a ton of a 3–8–5 fertilizer. To do this we merely multiply the number of pounds in a ton by the percent of each plant-food material.

$$\begin{aligned} 2000 \times .03 &= 60 \text{ pounds nitrogen per ton} \\ 2000 \times .08 &= 160 \text{ pounds phosphoric acid per ton} \\ 2000 \times .05 &= 100 \text{ pounds potash per ton} \end{aligned}$$

The next step is to calculate the number of pounds of the carrier required to furnish the quantity of plant-food material that has just been found. This is done by dividing the weight of the plant-food material required by the percent of this particular plant-food material in the carrier that is to be used.

$$\begin{aligned} 60 \div .15 &= 400 \text{ pounds nitrate soda} \\ 160 \div .14 &= 1143 \text{ pounds acid phosphate} \\ 100 \div .50 &= \underline{200} \text{ pounds muriate of potash} \\ & 1743 \text{ pounds of the three carriers} \end{aligned}$$

The weights of the different carriers are then added, giving in this case 1743 pounds needed for every ton of fertilizer. The remainder of the ton (2000 − 1743 = 257 pounds) is then made up with a filler, consisting of sand, dry earth, muck, peat, sawdust or something of the kind.

260. How to mix the ingredients. — A smooth tight floor is needed on which each carrier is spread in turn to break down the lumps. It is then passed through a coarse screen. A weighed quantity of the filler or principal carrier is then spread out in uniform depth and on top of it another carrier, until all are represented. Then the pile is shoveled over and over, and finally leveled and the process repeated until the ingredients are thoroughly mixed. This lot of fertilizer is then put in sacks and the operation repeated with another quantity until a sufficient amount is prepared. There should always be two hundred pounds or more of filler in each ton to give a more uniform distribution of the carriers.

QUESTIONS

1. In what parts of the United States are fertilizers used in greatest quantities?
2. What is meant by a brand of fertilizer?

3. What is a high-grade in distinction from a low-grade fertilizer?
4. Explain what is meant by a filler.
5. What, in a general way, does a report on the inspection of a fertilizer show?
6. How are trade values of plant nutrients evaluated?
7. What are the advantages to be derived from the home mixing of fertilizers?

LABORATORY EXERCISES

EXERCISE I. — Fertilizer inspection and control.

Fertilizer laws are designed to protect the honest manufacturer as well as the farmer. Obtain the laws of your state which have to do with fertilizer inspection and control. Analyze them step by step with this point always in mind. Decide whether or not the law does really regulate and protect in the way that it should. A study of fertilizer bags and tags could also be made with profit.

EXERCISE II. — Laboratory mixture of fertilizers.

Materials. — Sodium nitrate, dried blood, acid phosphate, muriate of potash, sulfate of potash, balances, dry soil as a filler. You must have the guaranteed composition of each carrier.

Procedure. — Make 2000-gram lots of the following mixtures. Fertilizers must be dry and fine. Put through sieve if necessary.

No. 1. — Make up 2 kilos of a 3–7–10 fertilizer, using sodium nitrate, acid phosphate and muriate of potash. Add filler as necessary.

No. 2. — Make up a fertilizer as above, using dried blood, acid phosphate and sulfate of potash.

Allow these mixtures to stand for some weeks and compare. Also compare them as to physical condition with a ready mixed fertilizer of a similar guarantee.

EXERCISE III. — Home mixture of fertilizers.

If possible coöperate with some farmer in the mixing of fertilizers. Allow the pupils to check all calculations and to aid in the actual mixing of the goods. The pupils should also understand the procedure of selecting and ordering the fertilizer carriers in order that every step in the process may be familiar to them. The educational value of a study of the crop, soil, fertilizer and rotation is a strong point in favor of home mixing.

CHAPTER XVI

THE USE OF FERTILIZERS

We have seen that a very considerable economy in the purchase of fertilizers may be effected through a knowledge of their composition. There is still further opportunity for both economy and profit through a study of their use.

261. Fertilizers for different crops. — It has already been pointed out that there is a difference in the ability of plants of different kinds to extract nutriment from the soil. Some crops are able to draw abundant nourishment from soils from which others derive but little. This may be due, in part, to (1) a deficiency in the soil of the particular substance most greatly needed by the crops, or (2) the inherent ability of one crop to make available plant-food materials, while another crop may possess that quality in much less degree. There are therefore two ultimate considerations in the selection of fertilizers: (1) the nature of the soil; (2) the kind of crop. The second of these will be discussed first.

262. Small grains. — Most of the small grains, like wheat, rye, oats and barley, need the principal part of their nitrogen early in the season, before the soil has warmed sufficiently to induce the germs that produce nitrates to lay up an abundant supply. Consequently the application of nitrate of soda, when growth begins in the spring, is very beneficial to these crops. Wheat in particular needs such an application. Since it is a "delicate feeder" it grows best after fallow, or a cultivated crop, and when it follows oats, as is

the usual custom, it needs a complete fertilizer. Rye is a "stronger feeder" and does not have the same need of fertilization. Oats and barley, when spring sown, find more nitrates in the soil, because they are later than winter wheat in starting growth, and, as they can make better use of the soil fertility, they do not require so much fertilizing.

Corn is a "strong feeder," and, while it removes a very large quantity of plant-food materials from the soil, it does not require that these be added in a soluble form. Farm manure and slowly acting fertilizers may well be used for the corn crop. The long growing period required by the corn plant gives it opportunity to utilize nitrogen as that substance becomes available during the summer, when nitrate formation is most active. Phosphoric acid is the substance usually most needed by corn.

263. Grass crops. — Meadows and pastures are greatly benefited by fertilizers. The grasses are less vigorous feeders than the cereals, have shorter roots, and, when left down for a year or more, the formation of nitrates is much curtailed. There is usually a more active fixation of nitrogen in grass land than in cultivated land, but nitrogen thus acquired becomes available very slowly. Different soils and different climatic conditions necessitate different methods of manuring for grass. The use of nitrate is almost always attended with much success, even when used alone, but in most situations a complete fertilizer is profitable.

264. Leguminous crops. — Most of the leguminous crops are deep-rooted and are vigorous "feeders." Their ability to acquire nitrogen from the air makes the use of that substance unnecessary except in the form of nitrate, which is often very effective in starting a young seeding of alfalfa. The nitrate probably serves to carry the young crop through the period preceding the development of tubercles. Potash salts are almost always profitably used on legumes, and

phosphoric acid is also likely to be effective. For such crops as clover and alfalfa there should always be an ample supply of lime, without which these crops cannot be profitably grown.

265. Root crops. — Most of the root crops remove very large quantities of plant-food materials from the soil, when these are present in available form. Like corn they have a long growing season and the slowly acting fertilizers or farm manure are well adapted to their use. A complete fertilizer in rather large quantity will usually bring a response in yield. For sugar beets the proportion of potash should be high, and for table beets and carrots there should be more nitrogen than for the other roots.

266. Vegetables. — In raising some kinds of vegetables, the object is to produce a rapid growth of leaves and stalks rather than fruit or seeds, and with these kinds growth should often be made in the early spring. Therefore, for crops like lettuce, radishes and asparagus a soluble form of nitrogen is very desirable. For crops that are raised later in the season a smaller proportion of nitrogen may be used, and for the more slowly growing kinds of vegetables the less soluble fertilizers may be applied. For all vegetables farm manure or other organic manure should be generously used, as it keeps the soil in a mechanical condition favorable to retention of moisture, which vegetables require in large quantities, and it also supplies needed fertility. The very intensive culture employed in the production of vegetables necessitates the use of much greater quantities of fertilizers and farm manure than are used for field crops, and the great value of the product justifies the practice.

267. Orchards. — In manuring orchards, it is the aim to maintain a continuous supply of nutrients available to the plants, but not sufficient for stimulation, except during the early life of the tree, when rapid growth of wood is

desired. During the first few years after setting out, there should be a liberal supply of nitrogen. An acre of apple trees in bearing removes as much plant-food material from the soil in one season as does an acre of wheat. Green-manures may be used to advantage in orchards, as by planting these crops in midsummer, moisture is removed from the soil and the wood of the trees is thereby hardened and thus prepared to withstand the low temperatures of winter. The green-manures also hold snow on the ground, if allowed to stand over winter, and may then be plowed under in the spring.

268. Fertilizer mixtures for different crops. — On account of the large number of factors that enter into the processes of crop production, it is obviously impossible to prescribe accurately the proportion and quantity of fertilizer carriers that should be applied. Some rough approximation can, however, be arrived at on the basis of the peculiarities of the various classes of crops that have just been enumerated. It must be remembered that different soil conditions may materially change the proportions of the fertilizer ingredients that should be applied. The following proportions of nitrogen, phosphoric acid and potash for different classes of crops have been proposed and have been found a fairly useful guide in the home mixing of fertilizers.

TABLE 43. — FERTILIZER FORMULAS FOR DIFFERENT CROPS

Crops	Percentage of Nitrogen	Percentage of Phosphoric Acid	Percentage of Potash
Legumes (young)	1	8	10
Small grains	3	8	5
Vegetables	4	8	10
Grass	5	4	4
Orchard	4	8	6
Roots	3	8	7

A fertilizer based on the first percentages would be called a 1–8–10 fertilizer; one based on the second a 3–8–5 fertilizer, and so on. In making up these formulas the carriers to use are indicated in the previous discussion. The quantities that it is desirable to use will depend so much on the natural productiveness of the soil that it is not possible to prescribe for soils in general. On soils of about average productiveness, however, a certain range for each of the classes of crops may be suggested.

Legumes	100 to 200 pounds per acre
Small grains	100 to 300 pounds per acre
Vegetables	500 to 1000 pounds per acre
Grass	200 to 500 pounds per acre
Orchards	200 to 600 pounds per acre
Roots	300 to 800 pounds per acre

269. Fertilizers for different soils. — The best way to ascertain what fertilizers are needed for a particular soil is to test it with different kinds and quantities of fertilizing materials. It will thus be possible to estimate whether the three substances, nitrogen, phosphoric acid and potash are all needed, and in about what quantities they should be applied.

A practical way is to select a level and apparently uniform part of a field and on it lay off plats of land eight rods long and one rod wide, giving an area of $\frac{1}{20}$ of an acre. These plats should lie parallel on their long side, but should have a space of at least three feet between them. The arrangement is shown in Fig. 31 on the next page, which also indicates the quantity of fertilizing substance that each plat should receive.

The fertilizer used in this experiment is designed for small grains, the mixture being 3–8–5 if the carriers contain about 15 percent nitrogen, 14 percent phosphoric acid and 48 percent potash respectively. If a legume or grass crop is

used in the test the fertilizer should be adjusted to suit the crop, as stated in Table 43. If grass is the most important

No fertilizer	
Nitrate of soda Acid phosphate	5 pounds 15 pounds
Nitrate of soda Muriate of potash	5 pounds $2\frac{1}{4}$ pounds
No fertilizer	
Acid phosphate Muriate of potash	15 pounds $2\frac{1}{4}$ pounds
Nitrate of soda Acid phosphate Muriate of potash	5 pounds 15 pounds $2\frac{1}{4}$ pounds
No fertilizer	
Nitrate of soda Acid phosphate Muriate of potash	$2\frac{1}{2}$ pounds $7\frac{1}{2}$ pounds 1 pound

FIG. 31. — Plan for a fertilizer experiment with small grains. Plats of land 8 rods long and 1 rod wide, giving an area of $\frac{1}{20}$ acre in each plat. The rate of application to the acre would therefore be twenty times the quantities given in the diagram.

crop the test should be made with special reference to it, and so with any other important crop. In any case a ro-

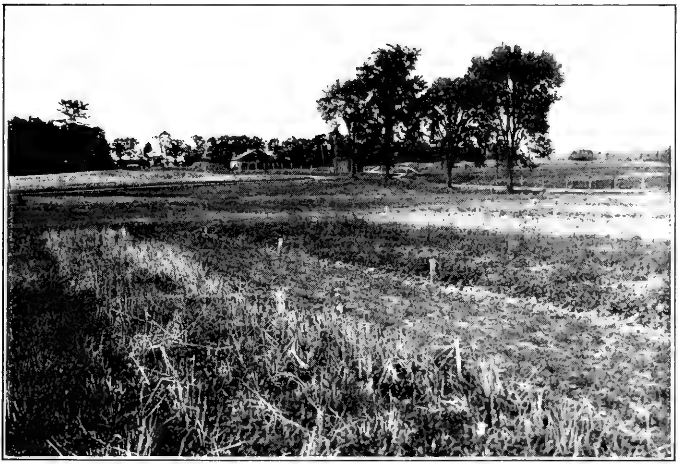


PLATE XIII. CROP WORK. — The upper figure shows a plat of timothy the left-hand side of which has been properly fertilized. The right-hand side has received no fertilizer. Note the thick stand of daisies on the latter.

The lower figure illustrates the method of laying off plats for tests of fertilizers.

tation should be followed and the system of fertilization should be adjusted to the rotation as explained in § 271.

In order that the kind and quantity of fertilizer shall be a controlling factor, the plats should be well drained and well tilled and should not be in need of lime, which may be ascertained by either of the tests described in §§ 145, 146.

270. Calculation of the results. — Each test plat has, on one side of it, a plat that has not been fertilized. The non-fertilized or check plats will not all give the same yield because the soil differs in various parts of the field. If the variations in yield between check plats are not greater than one bushel to the acre, they may be considered as being equal. If a greater difference exists, the yield from each check plat must be subtracted from the yields of the test plats beside it and the result may then be considered to be the increase due to the fertilizer application.

If the yield is as good, or nearly as good, on a check plat as it is on the corresponding test plat that lacks one of the fertilizing constituents, it may be concluded that the use of that constituent would not be a profitable investment. On the other hand, the very beneficial substances will be indicated by the increased yields wherever they are used. Finally the desirable quantities will be indicated by a comparison of the rates of increase on the plats receiving the full quantity and those receiving the half quantity of complete fertilizer. The tests should be continued for a period of three to five years in order that they shall be indicative of the fertilizer needs of the soil, and a rotation of crops should be used, with an adjustment of the fertilizer treatments to suit the different crops.

271. Fertilizing the rotation. — In a rotation of crops fertilizers need not be applied every year. For instance a rotation consisting of hay, two or three years, corn, oats and wheat would probably not receive any fertilizers on

one or two of the courses. It is desirable to make the relatively heaviest applications for the crops having the greatest money value. If the hay crop represents the largest possible returns, the crop should be well fertilized. Another reason for giving liberal applications to the hay crop is that the sod is thereby increased and furnishes a larger supply of organic matter to be plowed under (see § 204). Corn is the crop of greatest importance in some localities, in which case it should be well fertilized. Farm manure is usually the best fertilizer for corn, but farm manure should be supplemented by phosphoric acid either in the form of acid phosphate, basic slag or floats. Oats will seldom give a profitable response to fertilizers which may be dispensed with for that crop, but should be applied in the fall in preparation for wheat. It is hardly necessary to say that winter wheat should have the nitrogen applied in the spring in the form of nitrate of soda, while the phosphoric acid and potash should be harrowed in before planting.

272. Methods of applying fertilizers. — The distribution of fertilizers by means of machinery is much more satisfactory than is broadcasting by hand, because the former method gives a more uniform distribution. Cereal and other crops are now usually planted with a drill, or a planter provided with an attachment for dropping the fertilizer at the same time that the seed is sown, the fertilizer being, by this method, placed under the surface of the soil. Broadcasting machines are also used, which leave the fertilizer uniformly distributed on the surface of the ground, thus permitting it to be applied and harrowed in a sufficient time before the seed is planted to prevent injury to the seed through the chemical activity of the fertilizer.

Corn-planters with fertilizer attachment deposit the fertilizer beneath the seed, so as not to bring the two in contact. Grain drills do not do this and if the quantity of fertilizer

exceeds 300 or 400 pounds to the acre, it is better to apply it before seeding. Grass seed and other small seeds should be planted only after the fertilizer has been mixed with the soil for several days.

273. The limiting factor. — Attention has been called to the important influence that any condition unfavorable to plant growth is sure to exercise in curtailing yield of crops. If poor drainage is the difficulty, crop yields may be reduced to almost nothing, while if this be corrected a very productive piece of land may result. The same principle holds true when there is a deficiency of any one of the fertilizing substances. There may be present in a soil an abundant supply of available phosphoric acid and potash, but if nitrogen is deficient the crop yield is limited to the size of crop that the quantity of available nitrogen present will produce. Each of the essential plant-food materials exercises this control. It is, therefore, a requisite in the economical use of fertilizers to have a well-balanced mixture of plant nutrients. The balance must be adjusted to the needs of each particular soil, and to each kind of crop. Of course it is impossible to work out any fertilizer mixture that will fit these conditions exactly. These relationships are best worked out by field tests with fertilizer mixtures (see § 269).

274. The law of diminishing returns. — A small application of fertilizer usually effects a greater percentage increase of crop than does a larger application. This is unfortunate, because it means that there is a limit to the profitable use of fertilizers, for although the cost of the fertilizer rises in direct proportion to the quantity used, the rate of yield decreases after a certain point has been reached, and consequently the value of the product finally becomes less than the cost of the fertilizer. This law of diminishing returns may be illustrated by an experiment in which floats were applied in several different quantities to plats of land,

each of which plats also received an application of farm manure at the rate of 15 tons an acre. The applications of floats were at the rate of 200, 400, 800 and 2400 pounds to the acre respectively. In the following table are stated the increased yields over the check plats receiving the same quantity of farm manure but no floats. The values of the crops and cost of floats are reckoned on the same basis.

TABLE 44. — INCREASED YIELDS AND VALUES OF CORN RESULTING FROM APPLICATION OF FARM MANURE AND FLOATS

FERTILIZER TREATMENT PER ACRE	GRAIN BU.	VALUE	COST OF FLOATS	DIFFERENCE
15 tons of manure + 200 lbs. floats	7.0	$4.62	$ 0.90	$3.72
15 tons of manure + 400 lbs. floats	8.3	5.48	1.80	3.68
15 tons of manure + 800 lbs. floats	10.2	6.73	3.60	3.13
15 tons of manure + 2400 lbs. floats	12.7	8.38	10.80	2.42 loss

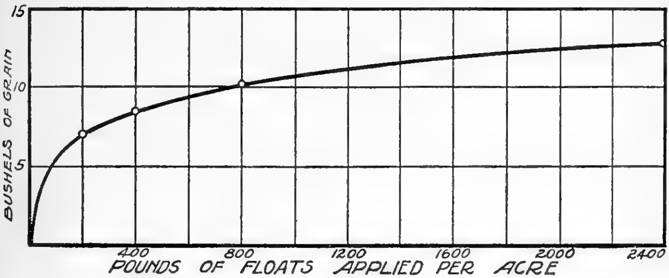
It may be seen that the increase from the use of the first 200 pounds of floats was greater than from the additional 200 pounds, and from the next 400 pounds the increase was at a still lower rate. This is best shown by a curve, which may be seen in the upper part of Fig. 32.

From the direction taken by the curve it may be seen that finally a point will be reached when there will no longer be any increase from larger applications of fertilizer. Long before that point is reached, however, the use of the fertilizer ceases to be profitable. This may be shown by another diagram containing curves for the value of the grain and the cost of the fertilizer. (See lower diagram in Fig. 32.)

This diagram as well as the last column of Table 44 shows that the difference between the value of the product and the

cost of the fertilizer decreases after the lowest application, and that for the very heavy application there is an actual loss.

275. Conditions that influence the effect of fertilizers. — The extent to which fertilizers are utilized by crops depends



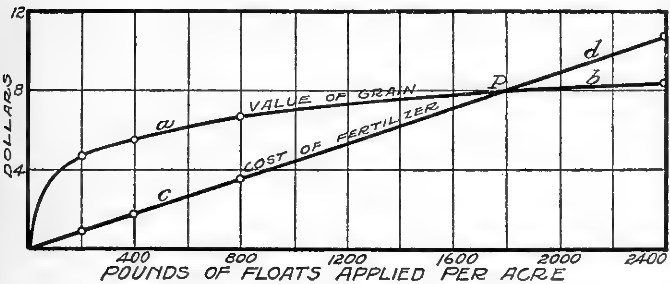


FIG. 32. — In the upper diagram the heavy line shows how the yields of corn were increased by graduated applications of phosphoric acid in floats. It will be seen that the increases in yields were proportionately much greater for small applications than for large.

The lower diagram illustrates the rate at which the cost of the fertilizer approaches and finally passes the value of the product as the size of the application increases.

on the presence or absence of certain conditions. The entire amount of any constituent of a fertilizer is never recovered by a crop in any one year. This is a very important consideration in the manuring of land, for under conditions as they frequently exist, the use of fertilizers is wasteful and extravagant.

The factors, within the control of man, that affect the availability of fertilizers are the following: (1) the kind of crops; (2) soil moisture content; (3) soil acidity; (4) tilth of the soil; (5) organic matter in the soil.

An undesirable condition of any one or more of these factors is a very common occurrence, and yet fertilizers are expected to produce profitable returns, in spite of these adverse conditions. It must be remembered that the supply of nutrients is only one of the conditions that influence plant growth. Furthermore, an economical use of fertilizers requires that they merely supplement the natural supply of plant nutrients in the soil, and that the latter should furnish the larger part of the nutrient material used by the crop. Finally, most fertilizers are rendered less readily soluble by the absorptive properties of the soil, and the release of these substances for plant use depends to a great extent on the conditions enumerated above.

276. Response of sandy and of clay soils to fertilizers. — It is generally recognized that a sandy soil responds more promptly to the application of fertilizers than does a clay soil. There are probably two reasons for this: (1) Absorption may not be so complete both on account of the particles being larger, and because in many sandy soils the particles are largely composed of quartz, which does not have the property of forming combinations with bases, as does clay; (2) Drainage and aëration are likely to be better, as are most of those conditions that make plant-food materials more available. For these reasons, a sandy soil generally makes a greater response to fertilizers the first year, but shows less effect in subsequent years unless the treatment is repeated. On the other hand, less fertilizing material is lost from a clay soil by leaching.

277. Cumulative need for fertilizers. — It is often remarked that on land habitually fertilized there is a gradually

A sufficient supply of moisture makes a fertilizer more effective. Note the greater response to fertilization in the vessels having more moisture.

Vessel 45. Moisture 30 per cent, no fertilizer.
Vessel 49. Moisture 15 per cent, no fertilizer.
Vessel 58. Moisture 30 per cent, complete fertilizer.
Vessel 64. Moisture 15 per cent, complete fertilizer.
Vessel 69. Moisture 30 per cent, more fertilizer.
Vessel 78. Moisture 15 per cent, more fertilizer.

PLATE XIV. — A soil may contain too much or too little moisture. The best crop is in the vessel having next to the largest quantity of water.

Vessel 20. Moisture 11 per cent.
Vessel 22. Moisture 13 per cent.
Vessel 24. Moisture 20 per cent.
Vessel 26. Moisture 25 per cent.
Vessel 28. Moisture 38 per cent.
Vessel 32. Moisture 45 per cent.

increasing need for greater quantities of fertilizers. This is doubtless the case in many instances, and arises from neglect of other factors affecting soil productiveness. As we have seen, certain fertilizers cause the soil to lose lime, which results in soil acidity. Organic matter is allowed to decrease, and this causes the soil to become compact and poorly aërated, and thus, one bad condition leads to another and crops become poorer in spite of increased applications of fertilizer.

QUESTIONS

1. Why are some crops able to draw abundant nourishment from soils on which other crops yield poorly ?
2. How do wheat and corn differ in their need of plant-food materials ?
3. Why is nitrate of soda particularly beneficial to grass ?
4. What two fertilizer materials are generally useful on legumes ?
5. What fertilizer material is required in large amounts by most root crops ?
6. What plant nutrient is especially needed by vegetables that are expected to make a rapid and succulent growth ?
7. In what ways are green-manures of use in orchards ?
8. Plan a fertilizer test similar to that shown in Fig. 31, but to be used with a crop of timothy instead of small grain.
9. To what crops in a rotation of corn, oats, wheat, and grass would you apply fertilizers?
10. Explain what is meant by the limiting factor in plant growth with respect to the use of fertilizers.
11. What is meant by the law of diminishing returns ?
12. Name five soil factors within the control of man that influence the availability of fertilizers.
13. Give two reasons why a sandy soil responds more promptly to fertilizers than does a clay soil.
14. Explain why soils sometimes demand an increasing use of fertilizers to maintain their productiveness.

LABORATORY EXERCISES

Exercise I. — Fertilization of standard rotations.

The fertilization of the rotation is the ultimate and final consideration of any systematic use of fertilizers. While the fertilization as

to amounts and mixtures is generally different for different farms, the place of fertilizers in a standard rotation is more or less fixed.

Take a number of good practical rotations and indicate where in the succession of crops the fertilization should occur. Also suggest what should be the formula of each mixture used, the fertilizer compounds which should be carried and the amounts that might be applied to a given soil.

Exercise II. — Fertilization of home-farms.

Encourage the pupils to bring in data regarding the fertilization on their home farms. Tabulate, discuss and criticize such data in a practical way. If any of the pupils have home project gardens, the fertilization of such gardens should be made a special problem for them.

Exercise III. — Fertilizer practice in the community.

A fertilizer survey of the township could be made with profit by the teacher, visiting each farmer and making inquiry adequate for the purpose in view. The pupils could aid not only in the collection of such data but also in such compilation and interpretation as would later be necessary.

Taking the class to visit a farmer whose system of farming and fertilization is a practical success is to be advocated. The economic use of fertilizers is attained not only by scientific knowledge, but also by good sound experience and practice.

Exercise IV. — Fertilizer experimentation.

The measurement in crop yield of the effects from fertilizer use is the only true means of gauging fertilizer needs and fertilizer practice. Whether a certain fertilizer pays is the ultimate question.

Lay out plans for fertilizer experimentation as suggested in the text with the idea of taking careful data as to crop yield from the various treatments used and the calculation of the net returns.

The fertilizer needs of the soil for nitrogen, phosphoric acid, potash and lime may be determined by the use of the various fertilizer carriers both alone and in combination. Different ready mixed fertilizers may also be compared. The amount of any particular fertilizer that may most economically be used can be tested by varying the applications of the same mixture. The relation of lime, farm manure and time of application to the effectiveness of any particular fertilizer may also be made a subject of experimentation.

CHAPTER XVII

FARM MANURES

THE use of animal manure to enrich the soil antedates written history, and it is still the most commonly and widely used fertilizer. It is produced on nearly every farm. Market-gardeners, who usually keep few animals, buy large quantities of horse manure from cities. Its use constitutes a way of returning to the land a part of the plant nutrients taken up by crops, as well as replacing some of the organic matter destroyed by cultivation. Farm manure contains nitrogen, phosphoric acid, potash, lime and the other ingredients removed from soils, and hence is a direct fertilizer. In addition to these it contains a large quantity of organic matter, which by its influence on tilth, moisture and absorptive properties is a valuable soil amendment, and finally it favors, in a number of ways, a vigorous bacterial activity that does much to bring plant nutrients into an available condition.

278. Solid and liquid manure. — Farm manure is made up of the solid excreta of animals, the urine, which is usually largely absorbed by the solid ingredients, and the litter used for bedding the animal. As these constituents differ greatly, not only in composition but also in physical properties, their proportions must appreciably affect the agricultural value of the manure. Litter usually does not have as high a fertilizer value as do the solid and liquid excreta. Of the excreta the larger part is solid and the smaller is urine. The ratios may be found in Table 45. The propor-

tion of litter is variable, depending on the extent to which bedding is used.

279. Chemical composition of manures. — From what has already been said regarding the variable nature of manure, it will be understood how difficult it is to give a statement of the composition of a representative sample of manure. The following table gives the results of an analysis that may be considered fairly representative of mixed fresh manure from several different classes of animals.

TABLE 45. — POUNDS OF WATER AND PLANT-FOOD MATERIALS IN ONE TON OF SOLID EXCRETA, ONE TON OF LIQUID EXCRETA AND IN ONE TON OF ENTIRE EXCRETA OF SEVERAL DIFFERENT CLASSES OF ANIMALS

Percentage of Solid and Liquid Parts of Excrement		Pounds in a Ton			
		Water	Nitrogen	Phosphoric Acid	Potash
Horse	Solid, 80 percent	1500	11	6	8
	Liquid, 20 percent	1800	27	trace	25
	Entire excreta	1560	14	5	11
Cow	Solid, 70 percent	1700	8	4	2
	Liquid, 30 percent	1840	20	trace	27
	Entire excreta	1720	12	3	9
Sheep	Solid, 67 percent	1200	15	10	9
	Liquid, 33 percent	1700	27	1	42
	Entire excreta	1360	19	7	20
Swine	Solid, 60 percent	1600	11	10	8
	Liquid, 40 percent	1940	8	2	9
	Entire excreta	1740	10	7	8

This table shows that the solid excrement constitutes by far the larger part of the total. It also shows that a ton of liquid excreta is generally richer in nitrogen and potash than

is an equal quantity of solid excrement, but in the case of swine there is little difference between the solid and liquid excreta in this respect.

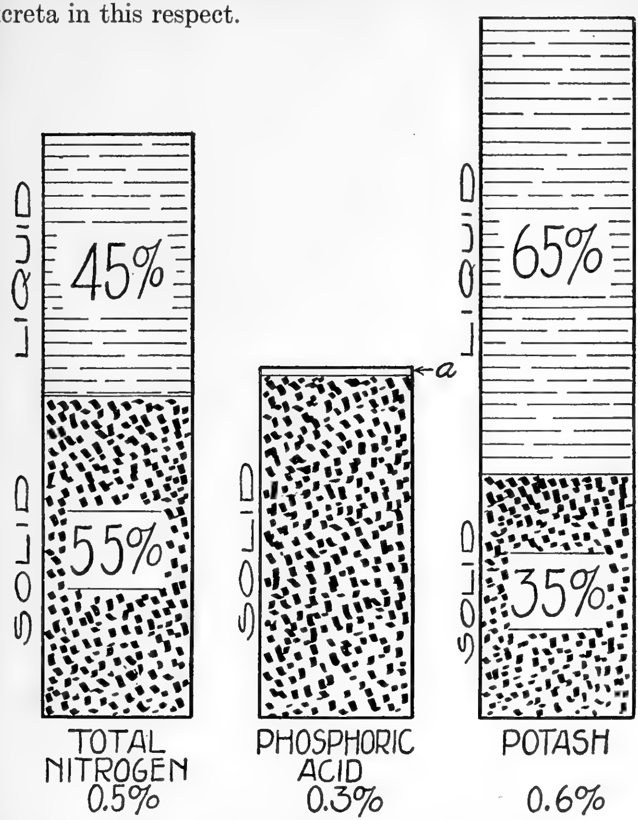


FIG. 33. — A farm manure containing 0.5 percent nitrogen, 0.3 percent phosphoric acid and 0.6 percent potash will, on the average, have these constituents divided between the solid and liquid parts of the manure in the proportions shown above.

280. Farm manure an unbalanced fertilizer. — A mixture of horse and cow manure, with an ordinary quantity of straw litter will have a composition somewhat as follows:

Constituents	Percent	Pounds Per Ton
Water	73.00	1460
Dry matter	27.00	540
Nitrogen	0.50	10
Phosphoric acid	0.25	5
Potash	0.60	12

Assuming that one-half of the nitrogen, one-fifth of the phosphoric acid and one-half of the potash are readily available, twenty tons of mixed manure would be equivalent to one ton of a 5–1–6 fertilizer. Comparing this with any ordinary fertilizer, it is evident that it is high in nitrogen and very low in available phosphoric acid. This suggests that for its most effective use farm manure should be supplemented by some form of phosphoric acid. As an illustration of the advantage of supplementing farm manure by phosphoric acid see Table 52.

281. Quantities of manure voided by animals. — An idea of the quantity of excreta, solid and liquid, produced by different animals may be obtained from the following table:

Table 46. — Excreta from Various Farm Animals to the 1000 Pounds Live Weight

Animal	Pounds per Day	Tons per Year
Horse	50	9.1
Cow	70	12.7
Steer	40	7.3
Swine	85	15.5
Sheep	34	6.2

282. Effect of food on composition of manure. — The richer the food in nitrogen and other plant-food materials, the more of these there will be in the manure. This has

been demonstrated by a number of experiments, from which the following have been selected.

TABLE 47. — EFFECT OF FOOD ON COMPOSITION OF ANIMAL AND POULTRY MANURE

RATION	POUNDS PER TON OF MANURE		
	Nitrogen	Phosphoric Acid	Potash
Fed to steers			
Corn and mixed hay	29.80	10.53	26.64
Corn, oil meal and hay	31.00	10.99	24.48
Corn, oil meal and clover	33.60	11.91	24.96
Fed to fowls			
Nitrogenous ration	16.00	18.78	6.48
Carbonaceous ration	13.20	14.65	5.04

283. Commercial evaluation of manures. — As a means of comparing manures, they may be evaluated in a manner similar to that used with commercial fertilizers. This, however, fails to place any value on the organic matter, which is undoubtedly of much benefit to the soil. In the following table are given the values of manures produced by different animals based, in part, on the composition given in Table 45 when the nitrogen is considered to be worth ten cents a pound, the phosphoric acid two and one-half cents and the potash four cents.

TABLE 48. — VALUE OF EXCRETA PRODUCED BY SEVERAL FARM ANIMALS

ANIMAL	VALUE PER TON
Swine excreta	$1.50
Cow excreta	1.64
Horse excreta	1.97
Sheep excreta	2.87
Poultry excreta	4.80

If the mixed horse and cow manure together with litter, similar to that referred to in section 280, be made the basis of the calculation, the evaluation would be $1.60. Dilution of the plant-food materials due to the litter tends to reduce the value.

284. Agricultural evaluation of manures. — The commercial value may be quite different from the agricultural value, which is calculated from the increased crop production resulting from the use of the manure. This will vary with different soils, but even on similar soils it will vary with different manures. The following table gives the results of an experiment in which treated and untreated manures were evaluated commercially and were then applied to the land. The value of the increased crops in a three years' rotation was then calculated in terms of financial return to the ton of manure applied:

TABLE 49. — COMMERCIAL AND AGRICULTURAL EVALUATION OF MANURES

MANURE	COMMERCIAL VALUE	AGRICULTURAL VALUE
Yard manure untreated	$1.41	$2.15
Yard manure plus floats	2.04	3.31
Yard manure plus acid phosphate	1.65	3.67
Yard manure plus kainit	1.45	2.79
Yard manure plus gypsum	1.48	2.76

285. Deterioration of farm manure. — There is always a loss in the value of farm manure on standing. The ways in which this is brought about are: (1) fermentation; (2) leaching. The first of these is a natural process, common to all farm manure on standing, and not occasioned by any outside agencies. The second is due to the running off of

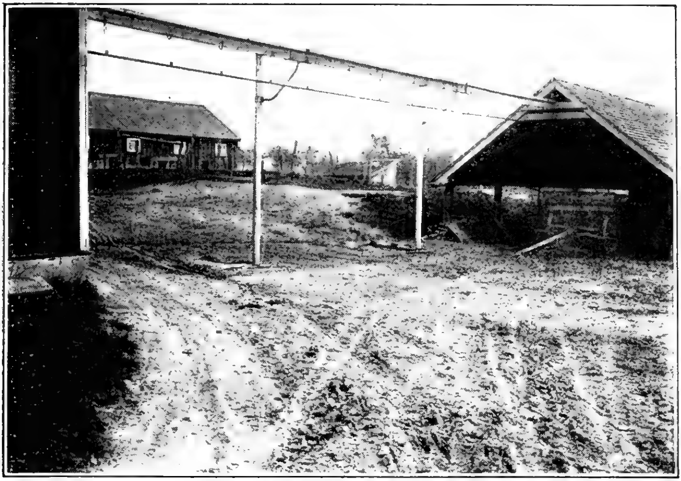


PLATE XV. MANURES. — Farm manure is becoming relatively more scarce every year. Its protection is becoming more essential to successful farming.

the liquid portion of the manure, and to the exposure of the manure to rain.

286. Fermentations of manure. — The mixture of solid and liquid excreta together with litter used as bedding constitutes a wonderfully favorable material for the growth of bacteria, the number of which frequently amounts to many billion in a gram of manure. This is many times more than are found in soil. It is then small wonder that fermentations proceed at a prodigious rate in a manure heap. These fermentations are produced both by bacteria requiring oxygen for their activity and by those that need little. The fermentations on the outside of the heap are different from those on the inside, where air does not readily penetrate, but as fresh manure is thrown on the pile from day to day, most of the manure first undergoes fermentation in the presence of air and afterwards without air.

It is through the action of germs on the nitrogenous compounds of manure that loss of value through fermentation occurs. In the presence of air ammonia is formed, and this being in a volatile form, is likely to escape. The drier the heap, the more likely the ammonia is to escape.

The fermentations in the interior of a moist manure heap are, in the main, favorable to the production of readily available plant-food material. It is desirable to keep the heap as compact as possible, and to prevent it from becoming dry by the application of water in amounts sufficient to keep the heap moderately moist without leaching it. In the arid and semi-arid parts of the country, this is an important precaution to be taken in the preservation of farm manure.

287. Leaching of farm manure. — When water is allowed to soak through a manure heap and to drain away from it, there is carried off in solution, and to some extent in suspension, more or less of the organic matter and plant-food

materials that are soluble in water and that consequently represent the most valuable part of the manure. As about one-half of the nitrogen and two-thirds of the potash of farm manure is in a soluble condition, the possibility of loss by leaching is very great. Even phosphoric acid may thus be removed.

It is rather difficult to distinguish between the losses due to fermentation and those caused by leaching. In an experiment conducted in Canada a carefully mixed quantity of farm manure was divided into two parts, one of which was placed in a bin under a shed, the other was exposed to the weather outside, in a similar bin. After a year the two portions were analyzed and the losses thus computed are stated in the following table.

TABLE 50. — LOSSES BY FERMENTATION ALONE AND BY FERMENTATION AND LEACHING COMBINED

CONSTITUENT LOST	PERCENTAGE LOSS	
	Protected	Unprotected
Organic matter	60	69
Nitrogen	23	40
Phosphoric acid	4	16
Potash	3	36

288. Protected manure more effective. — Over a period of fourteen years, in a three year rotation of corn, wheat and hay at the Ohio Experiment Station, stall manure gave an average yield of 30 percent more than did equal quantities of yard manure. This gives a fair basis on which to calculate whether it would pay to protect the manure when the expense of doing so, and the quantity of manure produced, are considered.

289. Reinforcing manure. — Various substances are incorporated with animal manures, either in the stall or in the heap, for the purposes of: (1) curtailing loss by leaching and fermentation, and (2) balancing the manure in order to better adapt it to the needs of most crops. The latter has been mentioned in section 280. The materials commonly used for these purposes are gypsum, kainit, acid phosphate and floats.

Experiments at the Ohio Experiment Station indicate that the conserving effect is slight, but that the benefit due to reinforcing is considerable when acid phosphate or floats are used. To ascertain the conserving properties of several substances, each was mixed with the manure at the rate of 40 pounds to the ton, and the loss of fertilizing value was computed from analyses after the mixtures had stood from January to April. The results are shown in the following table:

Table 51. — Effect of Reinforcing Materials on Conservation of Fertility in Farm Manure

Materials Used	Value of Ton of Manure		Percentage Loss
	In January	In April	
None	$2.19	$1.41	36
Gypsum	2.05	1.48	38
Kainit	2.24	1.45	35
Floats	2.81	2.04	24
Acid phosphate	2.34	1.65	29

The actual agricultural value of the reinforced manure was ascertained from tests covering a period of fourteen years in a rotation of corn, wheat and hay, of which the results were as follows:

TABLE 52. — FINANCIAL RESULTS OF REINFORCING FARM MANURE

	VALUE OF NET INCREASED YIELD TO THE TON OF MANURE
Manure alone	$3.31
Manure plus gypsum	3.56
Manure plus kainit	3.71
Manure plus floats	4.49
Manure plus acid phosphate	4.82

It has already been remarked that farm manure is deficient in available phosphoric acid, and this experiment demonstrates the benefit to be gained by reinforcing it with a phosphoric acid fertilizer.

290. Methods of handling manure. — The least opportunity for deterioration of farm manure occurs when it is hauled directly to the field from the stall and spread at once. Manure may even be spread on frozen ground or on snow, provided the land is fairly level and the snow is not too deep. However, it is not always possible to follow this method and manure must sometimes be stored. In the storage of manure the two important conditions are a sufficient but not an excessive supply of moisture, and a well-compacted mass. Water draining away from a manure heap, and a fermentation producing a white appearance of the manure under the surface of the pile (" fire fanging "), are both sure indications of unnecessary loss in its fertilizing value.

291. Covered barnyard. — The best method of storing manure is in a covered yard in which the cattle are allowed to exercise and thus to trample and compact the mixed manure from the barn. The advantage to be gained from the trampling is brought out by some Pennsylvania experiments in which the losses of fertilizing constituents were compared when the covered manure was trampled and when it was not.

Table 53. — Loss of Fertilizing Constituents from Farm Manure in Covered Sheds when Trampled and when Not Trampled

Treatment of Manure	Percentage Loss of		
	Nitrogen	Phosphoric Acid	Potash
Covered and trampled	5.7	5.5	8.5
Covered and not trampled	34.1	19.8	14.2

292. Application of manure to land. — In applying farm manure to the field, it is customary either to throw it from the wagon in small heaps, from which it is distributed later, or to scatter it as evenly as possible immediately on hauling it to the field. The use of the automatic manure-spreader accomplishes the latter procedure in an admirable manner. As between these two methods, the advantage, so far as the conservation of fertility is concerned, is with the practice of spreading immediately. When piled in small heaps, fermentation goes on under conditions that cannot be controlled, and that may be very unfavorable. The heaps may dry out, and thus lose much of their nitrogen, or they are likely to leave the field not uniformly fertilized because of the leaching of some of the constituents of the manure into the soil directly under and adjacent to the heap. On the other hand, when spread immediately, little fermentation takes place, as the manure does not heat, and the soluble substances are leached quite uniformly into the soil. Plowing should follow as closely as possible the spreading of the manure, except when it is intended for a top dressing.

293. Place of farm manure in crop rotation. — When a crop rotation includes grass or clover as one of the courses, the application of farm manure may well be made at that time as a dressing. It can thus be spread at times when cultivated land would not be accessible, and the crop of hay

will profit greatly. Sod, when plowed under, is frequently planted to corn — a crop that is rarely injured by farm manure. Experiments in Illinois indicate the great response of clover to farm manure, as compared with oats and corn.

TABLE 54. — INCREASED CROP YIELDS AND VALUES WHEN MANURE WAS APPLIED TO CORN AND OATS AND TO CLOVER

Treatment	Percentage Increase in Yield		Percentage Value of Increase	
	Corn and Oats	Clover	Corn and Oats	Clover
Manure	11	92	$ 7.53	$10.08
Manure, lime and phosphate	30	141	12.21	15.48

QUESTIONS

1. What plant nutrients does farm manure contain, and what indirect fertilizing material?
2. In what ways is the organic matter of farm manure beneficial to soils?
3. Which is richer in plant-food materials, liquid or solid manure?
4. What constituent should farm manure have added to it in order that it should be a well-balanced fertilizer?
5. What farm animal produces the largest quantity of manure for every 1000 pounds of live weight?
6. Which produces the more valuable manure, a ration rich in plant-food materials, or one poor in these substances?
7. Which of the farm animals furnishes a manure having the greatest commercial value a ton?
8. In what two ways does farm manure suffer loss on standing?
9. How is nitrogen likely to be lost by fermentation, and what condition is likely to bring this about?
10. What substances are lost by the leaching of manure?
11. What materials are used for conserving manure?
12. Is it better to store manure, or to haul it directly to the land? Why?
13. Discuss the place of manure in the crop rotation.

LABORATORY EXERCISES

Exercise I. — Study of farm manure.

In one or more trips through the community the class may study in a practical way the following points regarding farm manure and its utilization.

1. Enter a horse stable where fresh manure is lying in the stalls. Observe the odor of ammonia. Explain the reason for such an odor and its significance.

2. Compare horse manure and cattle manure as to weight, structural condition and amount of water. What relation may these characteristics have to fermentation and to the handling of the manures?

3. In the same way compare swine, sheep and poultry manures.

4. Examine the leachings from an exposed manure pile. What is the color of such liquid and what plant-food materials does it probably contain ?

5. Study the various ways of handling manure that are in vogue in the community. List and discuss their good and poor points, remembering that the method that would entail the least loss of plant-food material may not always be practicable, due to lack of capital or to the press of the season's work. The common ways of handling manure are : hauling directly to the field and either (1) spreading or (2) leaving in piles for later distribution, (3) storing in a covered barnyard, (4) storing in a manure pit, (5) allowing manure to be tramped down behind the animals or (6) storing in piles either under cover or exposed.

6. Study the mechanism and operation of a manure-spreader. An efficient spreader should run easily and yet distribute the manure evenly and in a finely divided condition.

Exercise II. — Experiments with farm manure.

Plat experiments similar to those suggested in Exercise IV, Chapter XVI might be carried out with profit with farm manure. The effect of different amounts of manure, the relative returns of manure from different classes of animals, the influence of lime on the return from the application of manure, and the residual influence of manure are only a few of the possible tests that might be made.

Tests as described in Exercise III, Chapter XI might be carried out with manure as well as with commercial fertilizers and lime if plats of soil are not available.

Exercise III. — The value of manure on the home-farm.

From the data in the text, have each student calculate the probable quantity of manure produced on his home-farm. Have him calculate the commercial value of this manure. Then from the way in which the manure is handled have him estimate the loss which occurs to this manure. Now discuss the probable agricultural value of the manure as compared with its original commercial value.

Exercise IV. — Reinforcement of farm manure.

In coöperation with some near-by farmer, reinforce some farm manure, allowing the pupils to aid not only in the actual work, but in the determination of the kind and amount of reinforcing materials to use. Calculate from the quantities used and their composition as given in the text, the probable composition of the manure after the treatment and determine whether it has become a properly balanced material. The reinforced manure should be spread in the field so that its influence on the succeeding crop may be compared with untreated manure. Reinforcements with different materials may even be compared under actual field conditions.

Exercise V. — Building of a compost pile.

Farm manure in a compost pile supplies the organisms which bring about the decay of the sod, leaves or other plant materials which are to be reduced to simple compounds. Composted materials are of especial value in greenhouses and gardens in supplying organic matter to the soil, that a good structure may be maintained.

Choose a level spot on which to locate the compost pile. First put down a layer of sod, moistening if necessary until optimum conditions are attained. Next apply a thin layer of fine, well-rotted manure, then sod and so on till the pile is complete. The pile may be as large as necessary or convenient and should be level on top to prevent the rainfall from running off the surface. If the interior of the pile is moist to begin with, it will stay moist through the period given to fermentation. Six months or a year are necessary for effective composting.

Other materials than sod may be placed in a compost heap, such as leaves, vines of all kinds, rotted vegetables, garbage, small sticks, etc. It is a good practice also to add lime to the pile to keep it sweet. If the material is to be used as a fertilizer as well as to condition the soil, acid phosphate may also be added.

CHAPTER XVIII

GREEN-MANURES

Crops that are grown primarily for the purpose of being plowed under to improve the soil are called green-manures. They may benefit the soil in one or more of four ways: (1) By utilizing soluble plant-food material that would otherwise leach from the soil; (2) by incorporating vegetable matter with the soil; (3) leguminous crops, when used, add to the available nitrogen of the soil; (4) plant-food materials from the lower soil may be brought to the surface soil.

A large number of crops may be used for this purpose, while the climate determines to some extent which crops should be used. Crops that can be planted in the fall to grow during the cool weather may be utilized when otherwise the land would frequently lie bare. Leguminous crops have the great advantage of acquiring nitrogen from the air. Deep-rooted crops usually accumulate a large amount of nutriment from the soil and considerable from the lower depths. They are therefore useful in bringing plant-food material to the upper layers of soil. Succulent crops decompose easily, and dry out the soil less, when plowed under, than do woody crops. Crops with extensive root-systems prevent loss of soluble matter more thoroughly than do plants with small root systems.

294. Protective action of green-manures. — It has been shown in section 121 that the growth of crops on land may prevent a large loss of plant-food material, especially nitrogen

and lime, in drainage water. If, therefore, green-manure crops cover the soil, when otherwise nothing would be growing on it, they exercise a protective action. In the case of orchards a green-manure crop saves much nutriment as compared with clean cultivation. A catch-crop, like rye, that is sown in the fall after a summer crop has been harvested and is plowed under in the spring, saves some plant-food material.

295. Materials supplied by green-manures. — Probably the most beneficial effect exerted by green-manures is the addition of organic matter to soil. Practically the only source of organic matter is in the form of farm manure or of plant residues. Farm manure is yearly becoming more scarce and expensive. Some substitute must be found. In an average crop of green-manure, from five to ten tons of material is turned under. Of this, from one to two tons is dry matter, and from four to eight tons is water. This would correspond to a dressing of four to eight tons of farm manure, so far as the organic matter alone is concerned.

Legumes add nitrogen as well as organic matter. The nitrogen contained in a ton of the green crop, when in a condition to plow under, is as follows:

TABLE 55. — QUANTITIES OF NITROGEN IN SOME LEGUMINOUS GREEN-MANURE CROPS

CROP	NITROGEN PER TON, POUNDS	PROBABLE YIELD PER ACRE, TONS	NITROGEN PER ACRE, POUNDS
Red or mammoth clover	10	6	60
Crimson clover	9	6	54
Alsike clover	10	5	50
Alfalfa	14	8	112
Cowpeas	8	6	48
Soy beans	10	6	60
Canada field peas	11	5	55

Not all of the nitrogen contained in these crops is taken from the air. On soils rich in nitrogen, a considerable proportion may be obtained from the soil. On poor soils, the proportion derived from the atmosphere is considerably larger. Soils needing nitrogen most are those that benefit most largely from its application.

296. Transfer of plant-food materials. — There is a transfer of plant nutrients in a double sense: (1) removal of these

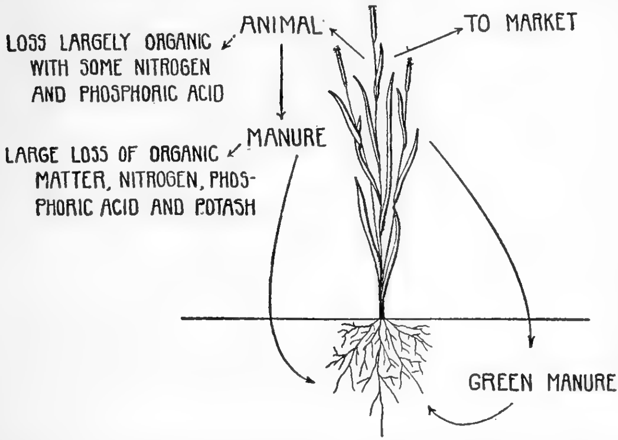


Fig. 34. — Movements of plant-food materials. After absorption by the plant they may be returned in whole or in part to the soil. If grain and straw or hay are sold nothing but the stubble and roots are returned. If fed to animals, part may be returned in the manure. If plowed under as green-manure, all are returned.

substances from combination with other minerals and their conversion into combinations with organic matter; (2) removal from lower soil by absorption by roots and the deposition of this material in the upper layer of soil when the plant dies and is plowed under. The first of these transfers results in an improved condition of the plant nutrients, because in the combinations with organic matter they are in general more available to plants than when in combinations with

inorganic matter. By the second form of transfer the nutrients in this available form are deposited in the upper soil from which most crops draw the larger part of their nutriment.

297. Crops used for green-manuring. — The following table contains a list of the plants commonly used as green-manures both in cultivated fields and in orchards, together with some information as to the season of the year when they may be used and whether adapted to northern or southern conditions.

TABLE 56. CROPS USED AS GREEN-MANURES

	SEASON	REGION
Legumes (annual)		
Canada field pea	summer	Northern states
Hairy vetch	winter	Northern and southern states
Crimson clover	winter	Middle and southern states
Peanut	summer	Middle and southern states
Velvet bean	summer	Middle and southern states
Soy bean	summer	Middle and southern states
Cowpeas	summer	Southern states
Legumes (biennial or perennial)		
Red or mammoth clover	one year at least	Northern states
Alsike clover	one year at least	Northern states
Alfalfa	one year at least	Northern and southern states
Sweet clover	one year at least	Northern and southern states
Non-Legumes		
Rye	winter	Northern and middle states
Oats	fall or early spring	Northern and middle states
Buckwheat	fall and summer	Northern states
Cowhorn turnips	summer	Northern states
Mustard	summer	Northern states
Rape	summer and fall	Northern states

A soil that has become less productive under cultivation, and that must be improved before profitable crops can be grown, receives more benefit from the use of legumes than from any other crop. The legume to use is naturally the one best adapted to the region in which the soil is located.

The perennial or biennial legumes are too slow of growth really to be considered green-manure crops. They are like

PLATE XVI. SOIL COVERS. — Cover-crops may consist merely of weeds allowed to grow voluntarily, as shown in the upper figure, or of grain or other planted crops, as shown in the lower.

timothy and other grasses and can well be grown for hay, only the sod being plowed under. Only in the case of very much run down soils are these crops plowed under. Crimson clover is an annual, and in the central and southern states may be sown in the fall and plowed under in the late spring, thus making use of a period of the year when the ground is least likely to be occupied by a crop. Cowpeas, soy beans and field peas must be raised during the summer months. Vetch promises to be a satisfactory green-manure for winter use in the northern states, when the cost of seed becomes less than it is at present.

Where it is desired to keep a crop on the soil during the autumn, winter and spring, for the purpose of utilizing the soluble plant-food material, the cereals, especially rye, are useful. Buckwheat, on account of its ability to grow on poor soil, is adapted to use as a green-manure, but it must be grown in the summer or early fall.

298. When green-manures may be used. — The most economical way to use green-manures is between the regular crops, rather than to lose a crop for the purpose of applying green-manure. Between a small grain crop and a spring-planted crop, there is usually opportunity for some green-manure to be raised, even in the northern states. This crop may be rye, vetch, buckwheat or rape and in the southern states may be added crimson clover, which is perhaps best for that region. In the South, however, there is much more opportunity for the use of green-manure crops on account of the longer season. Where timothy and red clover grow successfully, it is probably best to rely on the sod of these crops to furnish green-manure rather than to attempt any system that would necessitate dropping a crop from the rotation. By a judicious fertilization of the hay crops, a heavy sod may be produced, thus utilizing the inorganic matter of the fertilizer to produce organic matter in the sod.

It is probably where special crops are produced that green-manures will reach their greatest usefulness. Their use in orchards is well established. For this purpose they are plowed under in the spring and planted in midsummer. Potato-growers and even market-gardeners are using green-manures in increasing quantity.

299. Handling green-manure crops. — The stage of growth at which green-manures should be plowed under has a rather important bearing on their effect on the soil. In order that they shall decompose readily, they should be succulent when incorporated with the soil. If plants that have fully ripened are plowed under, they decompose very slowly and interfere with the formation of nitrates. An acid soil is unfavorable to the decomposition of green-manures and to the formation of nitrates; hence it is desirable that lime be applied before planting the manure crops unless the soil is already well supplied with lime.

QUESTIONS

1. Describe what is meant by green-manure crops.
2. State four ways in which they may be beneficial to the soil.
3. What two substances are prevented from being leached from soil in large quantities by the growth of green-manure crops?
4. How do legumes differ from other green-manures in contributing to soil fertility?
5. In what two ways is there a transfer of plant nutrients brought about by the use of green-manures, and how do they benefit the soil?
6. Name five leguminous green-manure crops and state the time of year in which they are generally planted in your locality.
7. Give the same information regarding five non-legumes.
8. What is the disadvantage of plowing under green-manure crops when they are fully ripe?

LABORATORY EXERCISES

Exercise I. — Study of green-manure in the field.

Plan a field trip to some farm where a crop is being turned under for green-manure. Determine whether the time is most favorable

for the operation. Study the action of the plow which is being used and see if the depth of the plowing, the inclination of the furrow slice, and the covering of the green material is as it should be.

Calculate the weight of the crop being turned under and with this as a basis, figure the pounds of water, dry matter, nitrogen, phosphoric acid and potash being placed in the soil per acre. If the crop is a legume, make a guess as to the probable gain of the soil in nitrogen. Is this nitrogen available or unavailable ?

Exercise II. — Green-manure and the rotation.

Take a number of good practical rotations and indicate where, in the succession of crops, a green-manure might be introduced. Encourage the pupils to bring data from their home farms for this study. Tabulate such material and study it in the class room. Also bring up the question in relation to gardening and trucking. Discuss the necessity, advisability and ways of introducing a green-manure under such conditions.

CHAPTER XIX

CROP ROTATION

EARLY in the development of agriculture, it was understood that a succession of different crops on any piece of land gave better returns than did one crop raised continuously. The practice of changing the crops raised each year thus became customary, and the prevalence of the method among European peoples shows that its benefits are widely appreciated. In Great Britain and some of the countries of Europe, crop rotations have been most systematically and effectively developed. Such development has been stimulated by the diminishing productiveness of the soil, consequent upon long-continued cultivation, coupled with an increasing and progressive population. Regions having undepleted and uninfested soil, as was formerly the case in the prairie region of the United States, and countries that have an unprogressive people, like those of India, have done little with crop rotation.

Another condition that discourages the use of crop rotation is the suitability of a region to the production of some one crop of outstanding value, combined, perhaps, with a relatively cheap supply of fertilizing material. These conditions obtain in the cotton belt of the United States. The abundant use of fertilizers may postpone for a long time the recourse to crop rotation.

300. Crop rotation and soil productiveness. — There are many benefits to be derived from a proper rotation of

crops that are not directly concerned with soil productiveness, and of these this book does not treat. In a number of ways crop rotation may directly affect the soil, and these will be discussed under several different heads.

301. Root systems of different crops. — Some crops have roots that penetrate deeply into the subsoil, while others are only moderately deep-rooted and still others very shallow-rooted. Among the deeply rooted plants are alfalfa, clover, certain of the root crops and some of the native prairie grasses. Among those having moderately long roots are oats, corn, wheat meadow fescue and a few other grasses, and among those having shallow roots are barley, turnips and many of the cultivated grasses.

As plants draw their nourishment from those portions of the soil into which their roots penetrate, the deeper soil is not called upon to provide food material for the shallow-rooted crops, and the deep-rooted crops remove relatively less of their nutrients from the surface soil. It, therefore, happens that a rotation involving the growth of deep and shallow-rooted plants effects, by utilizing a larger area of the soil, a more economical utilization of plant nutrients than would a continuous growth of either kind.

302. Nutrients removed from soil by different crops. — Some crops require large amounts of one fertilizing constituent, while others take up more of another. For instance, wheat crops are able to utilize the potassium and phosphorus of the soil to a considerable degree, but have less ability to secure nitrogen. They are usually much benefited by the application of a nitrate fertilizer and leave in the soil a considerable residue of nitrogen that may be available to other plants. A number of other crops, as, for example, beets and carrots, can utilize this residual nitrogen.

Grasses remove comparatively little phosphoric acid. Potatoes remove very large quantities of potash. A rota-

tion of crops is, therefore, less likely to cause a deficiency of some one constituent than is a continuous growth of one crop, and it utilizes more completely the available nutrients.

303. Some crops or crop treatments prepare nutriment for other crops. — It is quite evident that leguminous crops not only leave in the soil an accumulation of organic nitrogen transformed by bacteria from atmospheric nitrogen, but that they leave part of the nitrogen in a form readily available for use by other plants. The presence of a grass crop on the land for several years favors the action of non-symbiotic nitrogen-fixing bacteria. The grass crops also leave a very considerable amount of organic matter in the soil, which by its gradual decomposition contributes both directly and indirectly to the supply of available nutrients.

Stirring the soil at intervals during the summer greatly facilitates decomposition, and leaves a supply of easily available food material. The introduction of intertilled crops in the rotation thus serves to prepare nutriment for those that receive no intertillage.

304. Crops differ in their effect on soil structure. — Plants must be included among the factors that affect the arrangement of soil particles. The result of root growth is usually to improve the physical condition of soil. In general, crops with rather shallow and very fibrous roots are most beneficial, at least to the surface soil. Millet, buckwheat, barley and to a less extent, wheat leave the soil in a friable condition. It is on heavy soils that this property is most beneficially exercised. Tap-rooted plants, and others with few surface roots, do not exhibit this action. Alfalfa and some root crops are likely to leave the soil rather compact as compared with the crops mentioned above. The effect of sod is nearly always beneficial to heavy soils, and this is one of the reasons for using a grass crop in a rotation.

305. Certain crops check certain weeds. — By rotating crops the weeds that flourish during the presence of one crop on the land may be greatly checked by succeeding crops. Some weeds are best destroyed by smothering, for which purpose small grain, and notably corn or sorghum grown for fodder are effective. Other weeds are most injured by tillage, to accomplish which the hoed crops are needed; while others can best be checked by the presence of a thick sod on the ground for a number of years. In the warfare against weeds that must be waged wherever crops are raised, the use of different crops involving different methods of soil treatment is of great service.

306. Plant diseases and insects. — Many plant diseases and many insects spend their resting stages and larval existence in the soil. A continuous growth of any one crop on the soil favors the increase of these species by providing each year the particular plant on which they thrive. A change of crops, by removing the host plants, causes the disappearance of many diseases and insects through their inability to reach their host plants. A long rotation, such as is frequently used in Great Britain, is particularly effective in eradicating those diseases that persist in the soil for a number of years.

In the case of diseases that affect more than one species of plant, as does the beet and potato scab, there is need for special care in arranging the rotation. Such considerations may make it desirable to change the plan of a rotation. Another feature of the relation of crop-rotation to plant diseases is that the more thrifty growth obtainable under rotation assists the crop to withstand many diseases.

307. Loss of plant-food material between plantings.—Many systems of crop rotation permit a more constant use of the land than is possible with continuous growth of most annual crops. As a soil bearing no crop on it always loses more plant-food material in the drainage water than does one on

which plants grow, it is thus possible, by a well-chosen rotation, to save plant-food material that would otherwise be lost.

308. Production of toxic substances from plants. — That soil sometimes contains organic substances that exert an injurious effect on the growth of certain plants is indicated by recent experiments and was surmised by some early writers on the subject. De Candolle was probably the first to advance the idea in 1832. He suggested that at least some plants excrete from their roots substances that are injurious to the growth of the plants themselves and others of their species, although the excreta may be harmless or even beneficial to other plants. This he considered one of the reasons for the failure of many crops to succeed when grown continuously, while the same soil may be productive under a rotation of crops.

Of recent years this subject has been investigated extensively in the United States and to some extent in Europe. There appears to be no doubt that toxic substances of an organic nature sometimes occur in soils, and there is evidence that some of them are connected with the growth of certain crops to which they are injurious. In most soils containing toxic substances the injurious effect is exerted on a large number of plants rather than only on those that have been previously grown. It is still a question to what extent excretion from roots or partial decomposition of plant residues are responsible for the poor growth that results from the continuous growth of crops on the same soil.

309. Management of a crop rotation. — The advantages of a crop rotation are so apparent and are connected so closely with the profits to be derived from farming that there can be no doubt regarding the advisability of practicing a rotation, even when some one crop may be much more profitable than any others that can be grown. Thus even in regions and on

soil particularly favorable to the production of any one crop, like tobacco, cotton, hay, corn or wheat, it will seldom be advisable to raise one crop to the exclusion of others, but the most rational practice will generally provide for some system of crop rotation.

There are three classes of crops that should, so far as possible, have a place in any rotation. These are legumes, sod crops or grasses and intertilled crops. The value of legumes as nitrogen gatherers has already been discussed. It is particularly on poor land that legumes are of most benefit, and if some of the tops, as for instance, the second growth of clover, be plowed under, their value will be greater.

Sod crops are of great value in furnishing organic matter to the soil. The larger the hay crop, the more sod produced, which is a double incentive to the use of fertilizers and farm manure on this crop (see § 204). Sod also forms a favorable condition for the fixation of nitrogen. Legumes appear to have one advantage over sod crops as nitrogen gatherers, in that the nitrogenous matter remaining in the soil is more available to some crops, at least, and is more readily converted into nitrates.

In each course of a rotation there should be, if possible, one intertilled crop, like corn, cotton, potatoes or cabbage. The intertilled crop should follow the sod crop, or the legume, because the cultivation given the soil throughout the summer produces a condition favorable to the decomposition of the organic matter furnished by the sod. Except where the conservation of moisture is an important factor, the use of an intertilled crop is preferable to a clean fallow, as it is more economical of the nitrogen and lime supply, and appears to result in better crops the year following.

Other crops to be used in the rotation will be determined by the climate, soil, market and convenience in handling.

Fertilization of the rotation is discussed in section 271.

QUESTIONS

1. What advantage is gained by alternating deep-rooted with shallow-rooted plants in a rotation ?

2. Why is a rotation of crops less likely to cause a deficiency in some one constituent of the soil than is the continuous growth of one crop ?

3. In what ways do some crops and some crop treatments prepare available nutriment for other crops ?

4. How may soil structure be affected by crop rotation ?

5. Explain the relation of crop rotation to weeds.

6. Explain the relation of crop rotation to plant diseases and insects.

7. How may plant nutrients be prevented from leaching by the use of the proper rotation ?

8. What three classes of crops should have a place in any rotation and why ?

LABORATORY EXERCISES

Exercise I. — Crop rotations.

Study standard crop rotations from different parts of the United States as to crops grown, climate, markets, fertility of the soil, fertilization, etc. Try to find the reason for the use of each rotation under its particular conditions.

With the aid of the pupils, obtain a number of the rotations used in the community or county. Study these from all standpoints, and, if possible, suggest improvements. A rotation survey of the community might be made in order that data valuable to the farmers, as well as to the pupils, shall be obtained. The students should aid in this as well as in the tabulation and interpretation of the data.

Exercise II. — Fertilizing the rotation.

Under given conditions have the pupil work out the fertilization of a standard rotation for the locality. This means not only the kinds and quantities of fertilizer to apply, at what point in the rotation to add them and at what time of year to put on the soil, but also the use of lime, green manure and farm manure. Such a study should be a summation of many of the practices and principles of good soil management.

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